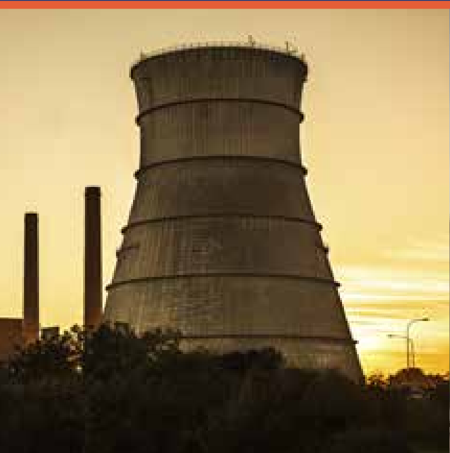
RECORD renewable energy center of research & development

sanedi South African National Energy Development Institute (SOC) Ltd

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH



The State of Energy Research in South Africa

August 2014

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science for the benefit of society, with a mandate encompassing all fields of scientific enquiry in a seamless way, and including in its ranks the full diversity of South Africa's distinguished scientists.

The Parliament of South Africa passed the Academy of Science of South Africa Act (*Act 67 of 2001*), as amended, and the Act came into force on 15 May 2002. This has made ASSAf the official Academy of Science of South Africa, recognised by government and representing South Africa in the international community of science academies.

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List of Acronyms

AIDC	Automotive Industry Development Centre
ARC	Agricultural Research Council
ASSAf	Academy of Science of South Africa
BRICS	Brazil, Russia, India, China, South Africa
CCGT	Closed cycle gas turbine
CCS	Carbon capture and storage
CEF	Central Energy Fund
CNR-IFN	*Consiglio Nazionale delle Ricerche – Istituto di Fotonica e Nanotecnologie* National Research Council – Institute for Photonics and Nanotechnologies
CoC	Centre of Competence
CoE	Centre of excellence
CPV	Concentrator photovoltaic
CPUT	Cape Peninsula University of Technology
CREST	Centre for Research on Evaluation, Science and Technology
CRSES	Centre for Renewable and Sustainable Energy Studies
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated solar power
CUT	Central University of Technology
DAFF	Department of Agriculture, Forestry and Fisheries
Da Vinci	Da Vinci Institute for Technology Management
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DoE	Department of Energy
DPE	Department of Public Enterprises
DST	Department of Science and Technology
DUT	Durban University of Technology
EE	Energy efficiency
EEDSM	Energy efficiency and demand side management
ENEL	*Ente Nazionale l'Energia Elettrica*
EPPEI	Eskom Power Plant Engineering Institute
ERC	Energy Research Centre
EU	European Union
FTE	Full-time equivalent
GDP	Gross domestic product
GERD	Gross expenditure on research and development
GHG	Greenhouse gas
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit*
CO_2e	Carbon dioxide equivalent
HCD	Human capital development
HEI	Higher education institute
HSRC	Human Sciences Research Council
HySA	Hydrogen South Africa
IDC	Industrial Development Corporation
IEA	International Energy Agency
IEP	Integrated Energy Plan
IP	Intellectual property
IPC	International Patent Classification
IPP	Independent power producer
IRP	Integrated Resource Plan
JIF	Journal impact factor
KAERI	Korean Atomic Energy Research Institute
KZN-DEDT	KwaZulu-Natal Department of Economic Development and Tourism
M&D	Masters and doctoral
M&V	Measurement and verification
MERSETA	Manufacturing, Engineering and Related Services: Sector Education and Training Authority
MLIS	Molecular Laser Isotope Separation
MNCS	Mean normalised citation score
MSC	Mean citation score
MUT	Mangosuthu University of Technology
NACI	National Advisory Council on Innovation
NDP	National Development Plan

Necsa	South African Nuclear Energy Corporation
NERDIS	Nuclear Energy Research and Development Strategy
NERSA	National Energy Regulator of South Africa
NDP	National Development Plan
NMMU	Nelson Mandela Metropolitan University
NNR	National Nuclear Regulator
NPC	National Planning Commission
NREL	National Renewable Energy Laboratory
NRF	National Research Foundation
NSI	National System of Innovation
NT	National Treasury
NWU	North-West University
OCGT	Open cycle gas turbine
OECD	Organisation for Economic Co-operation and Development
PBMR	Pebble-bed modular reactor
PCT	Patent Co-operation Treaty
PGM	Platinum group metal
PV	Photovoltaic
R&D	Research and development
RECORD	Renewable Energy Centre of Research and Development
RE	Renewable energy
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RRT	Radiation and Reactor Theory
RU	Rhodes University
SA	South Africa
SACCCS	South African Centre for Carbon Capture and Storage
SACPS	South African Coal Processing Society
SADC	Southern African Development Community
SAGEN	South African-German Energy Programme
SAMMRI	South African Minerals to Metals Research Institute
SANEDI	South African National Energy Development Institute
SANERI	South African National Energy Research Institute
SARChI	South African Research Chairs Initiative
SARi	South Africa Renewables Initiative
SASA	South African Sugar Association
S&T	Science and technology
SMRI	Sugar Milling Research Institute
SU	Stellenbosch University
the dti	Department of Trade and Industry
THRIP	Technology and Human Resources for Industry Programme
TIA	Technology Innovation Agency
TUT	Tshwane University of Technology
UCG	Underground coal gasification
UCT	University of Cape Town
UFH	University of Fort Hare
UFS	University of the Free State
UJ	University of Johannesburg
UJ URC	University of Johannesburg, University Research Committee
UK	United Kingdom
UKZN	University of KwaZulu-Natal
UL	University of Limpopo
Unisa	University of South Africa
UniVen	University of Venda
UP	University of Pretoria
USA	United States of America
UWC	University of the Western Cape
UZ	University of Zululand
VUT	Vaal University of Technology
Wits	University of the Witwatersrand
WoS	Web of Science
WRC	Water Research Commission
WWF	World Wildlife Fund

Prefixes, Units and Gases

Gases		
Prefix	**Symbol**	**Power**
Kilo	K	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}

Units in measurements	
Unit	**Definition**
h	hour
t	ton
W	Watt

Gases	
Unit	**Definition**
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
NO_x	Nitrogen oxides
SO_x	Sulphur oxides

Currency	
Unit	**Definition**
R	Rand
$	Dollar
€	Euro
DM	Deutschmark (West Germany: 1948–1990)
KRW	South Korea won

Foreword

The Academy of Science of South Africa (ASSAf) is mandated to provide evidence-based advice to government on matters of critical national importance. Given the importance of energy in promoting economic development and contributing towards an improved quality of life, a study on the state of energy research in South Africa is poised to make a vital contribution to energy planning in South Africa. Gaps in energy research and areas of particular strength in South Africa have been identified.

The study has followed the traditional Academy consensus study methodology, in which a panel of experts, guided by the panel chair, undertakes the study on a voluntary basis. The advantage of this multiperspective approach is that it is free of partisan interest. As a result, the findings and recommendations are the best considered outcomes in the circumstances.

This report can be regarded as an important baseline assessment that can inform future energy research investment in South Africa. Such an assessment should be conducted on a regular basis to ensure that it is current and provides information useful for decision-makers. Although considerable effort has been expended in trying to compile a comprehensive report, it must be recognised that a status report of this nature is heavily dependent on stakeholder participation to supply data. Hence it is important to view this report as the first in a potential series of such reports and an opportunity to place a 'peg in the sand'.

The members of the study panel and the authors of the report, as well as the staff of the Academy, are acknowledged for the valuable work that they have done and for the care and attention with which they carried out their task.

Professor Daya Reddy
President: Academy of Science of South Africa

Acknowledgements

This report is the result of the collaborative work of a six-member ASSAf study panel. The study panel members were: Professor Frederik van Niekerk (Chair), Professor Susan Harrison, Dr Nelson Ijumba, Dr Steve Lennon, Professor Regina Maphanga and Professor Wikus van Niekerk.

All panel members agreed on the report's findings, conclusions and recommendations. They are all hereby acknowledged and thanked for their contributions to this study and subsequently this important report.

Professor Frederik van Niekerk is particularly acknowledged for the additional time and effort that he dedicated in ensuring that this report is of the highest standard.

The study panel would also like to thank the following individuals for their contribution and assistance in completing this report:

The peer-reviewers, Dr Van Zyl de Villiers, Professor Dieter Holm and Professor Rosemary Falcon for their inputs that greatly enriched the report.

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DM Kisch Patent Attorneys for their work on the intellectual property scan and the Stellenbosch: Centre for Research on Science and Technology (CREST) for their contribution on the bibliometric profile of the state of energy research in South Africa.

The ASSAf editorial and production team led by Ms Patricia Scholtz for all the work they did on the report. The ASSAf secretariat, especially Prof Roseanne Diab, Ms Henriëtte Wagener and Ms Nadia Weitz, for their contributions to the successful completion of the report. The panel also thanks the ASSAf Council for their support.

The panel acknowledges the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)* for the funding provided to ASSAf for the execution of this study.

Executive Summary

The Academy of Science of South Africa (ASSAf) was tasked with providing an overview of current energy research being undertaken in South Africa (SA), including budgetary allocations; to profile energy researchers; identify gaps, and make recommendations on future energy focal areas for South Africa. The motivation for the project is to improve the understanding of the energy research landscape in South Africa, in order to support the South African National Energy Development Institute (SANEDI) to fulfil its functions in terms of energy research support and co-ordination in South Africa. The scope of the study did not require international comparisons, although in some cases such comparisons were readily available due to the nature of the data and analyses (e.g. the bibliometric analyses).

The South African science and technology (S&T) landscape was briefly introduced to provide perspective to the study. The most important documents defining the South African roadmap for energy and energy-related research were highlighted: the Department of Science and Technology (DST) 10-Year Innovation Plan; the Department of Energy (DoE) Integrated Resource Plan (IRP); the National Development Plan (NDP); and the National Energy Act (*Act 34 of 2008*).

The updated IRP released in 2013 indicates, *inter alia*, a continued focus on renewable energy, with allocations for additional photovoltaic (PV), wind and concentrated solar power (CSP) capacity; a possible delay in the nuclear decision until after 2025 or even 2035, by exploring alternative options, such as regional hydro and further exploration of the shale gas potential; and an allocation for a new set of fluidised-bed combustion coal generation. The NDP has a similar focus, identifying innovation and technology for cleaner coal use as key drivers for achieving a greener energy dispensation by 2030. The plan also mentions gas as a key alternative to coal. Specific mention is made of off-shore natural gas, coalbed methane, shale gas resources in the Karoo Basin and imports of liquefied natural gas, which could be used for power production, gas-to-liquids refineries and other industries.

The study was divided into five broad fields, *viz*. Renewable Energy (wind, wave, solar, etc.), Renewable Energy (bio), Nuclear Energy, Fossil Fuels, and Energy Efficiency and Storage. Data were gathered using a combination of desktop studies, interviews and a questionnaire-based survey. In addition, a bibliometric study of energy research in South Africa was conducted; a scan of energy and energy-related intellectual property (IP) was undertaken; and a scan of energy and energy-related Masters and doctoral theses/dissertations was undertaken. The scope of the study was agreed with the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)*. Due to constraints related to the availability of data, different time spans were allowed for data collection.

There are seven Department of Science and Technology (DST)/National Research Foundation (NRF) chairs in energy or energy-related research, spread across five higher education institutions (HEIs); three DST Centres of Competence (CoCs); and at least seven other centres, clusters or units with an energy research focus spread across the science system. In addition, Eskom has established a Power Plant Engineering Institute and supports eight chairs at HEIs.

The 2010/11 National Survey of Research and Experimental Development (HSRC, 2013) shows that South Africa spent R898.2 million as gross expenditure on research and development (GERD) on energy, amounting to 4.4% of the total GERD. The report indicates a decline of R49.4 million (-5.2%)

from the R947.5 million of 2009/10. The compound annual growth rate (CAGR) on expenditure on research and development (R&D) on energy from 2001/02 until 2010/11 is 11.7%, however, CAGR had decreased since 2008/09.

The bibliometric study conducted over the period 2000–2011, selected to provide as long a period as possible so as to ascertain trends, yielded a total of 1 965 papers published in the broad field of energy. Key findings are that there has been a steady increase in South Africa's publication output from 82 papers in 2000 to 293 papers in 2011 (257% increase); the outputs in the fields of Electrochemistry and Energy & Fuels account for the largest increases; five institutions account for nearly two-thirds of publication output, with the university sector dominating output (88%); South Africa ranks 38th in the world for energy papers produced over the period 2000–2011, but when controlling for size of workforce, South Africa records higher levels of productivity compared to the traditional 'power houses' in energy research (e.g. USA, China, Germany, Japan, the UK and France), producing 5.75 papers per 100 of the full-time equivalent (FTE) research workforce compared to only 3.28 and 2.99 in the case of the USA and China.

In terms of Masters and doctoral output, seven HEIs account for approximately 75% of the completed energy-related degrees over the period 2006–2013. The bulk of the research is taking place in renewables (32%), and storage and hydrogen and fuel cells (19%), with the fields of nuclear energy, energy efficiency and modelling and control, each having a greater than 10% share. Postgraduate research, as measured by Masters and doctoral output shows no growth over this period; research in nuclear energy is declining, while research in renewable energy is on the increase. Institutional strengths in renewable energy are at SU, UCT and Wits; nuclear energy at NWU; fossil-based energy at Wits and NWU; energy efficiency at NWU, Wits, UCT, UP and UJ; storage and hydrogen and fuel cells at VUT, UWC, Wits, UCT, NWU and UJ; energy and the environment at Wits, UCT and UP; and modelling and control at CPUT, UCT and Wits.

In terms of patents in the energy field, the private sector dominates, accounting for 76% of registered patents over the period 2000–2014, followed by HEIs with 13% of the total and the public sector, including science councils, accounting for the balance of 11%. Sasol has generated the most patents, followed closely by the Pebble-bed Modular Reactor (PBMR), which embarked on a patenting drive to protect its future business prior to its closure.

The questionnaire survey and desktop study have generated some significant findings:

- Given the fact that coal is going to dominate our energy supply well beyond 2030, investments in coal R&D are insufficient. Clean coal technologies are not sufficiently funded; carbon capture and storage research programmes are insufficient and the bulk of the coal R&D is being performed by only four entities, namely Eskom, Sasol, Wits and NWU.
- Very little/insufficient attention is given to research into shale gas, which, based on preliminary studies and surveys, has the potential to provide a lower carbon medium-term energy future for South Africa.
- Research in renewable energy is growing, albeit at a pace lower than needed to meet national targets and expectations.
- Human capital development, as well as R&D in nuclear energy is diminishing and the country is losing critical skills in this field.

- Energy efficiency efforts and commitments are centred on managing loads until new capacities come online. There is a need for a shift towards energy efficiency as a tool for long-term planning. The category Energy Efficiency accounts for less than 0.5% of the total number of energy-related patents registered by South Africans from 2000 to October 2013.
- Despite energy being identified as one of DST's Grand Challenges and the prominence given to energy in the NDP and other policy documents, the energy and energy-related Masters and doctoral degree output is not growing.
- In general, coordination and cooperation in energy and energy-related R&D is insufficient, resulting in overlaps/duplication and gaps in terms of national priorities. This is partly due to the fact that the energy and energy-related R&D budgets are located within multiple state departments and state-owned enterprises.
- A number of research strengths have been identified. The South African National Energy Development Institute (SANEDI) is supporting a significant and well-coordinated suite of energy projects, aligned with national priorities, notwithstanding their very limited budget. These include bio-energy, renewable energy, fossil-based energy, energy storage and energy efficiency. The budgetary allocations made to SANEDI since 2011 to date, as well as planned until 2015/16 are inadequate to execute the SANEDI mandate in terms of the National Energy Act. The optimal resourcing and placement of SANEDI in the national research agenda is of paramount importance.
- Eskom, too, has a well-coordinated energy research programme focused on fossil fuels and renewable energy. The Hydrogen South Africa (HySA) hydrogen programme established by the DST has significant funding and comprises three CoCs functioning according to the hub-and-spoke model. In addition, based on Masters and doctoral degrees conferred, patents developed, as well as publication output, the following institutions have energy or energy-related strengths, aligned with national priorities:
  - Sasol (fossil fuels and Fischer-Tropsch)
  - NWU (nuclear energy, coal technology, renewable energy, energy efficiency)
  - SU (renewable energy)
  - UCT (energy policy, renewable energy)
  - UWC (hydrogen and fuel cells)
  - Wits (renewable energy, fossil fuels)
  - UP (energy efficiency).

The key recommendations relate to:

- **Coordination:** First, it is proposed that government departments with an energy budget establish a formal coordination mechanism, in accordance with the recommendations of the NDP, with a mandate to steer, plan and coordinate energy and energy-related R&D funded with public money, eliminating gaps and overlaps, taking into account national imperatives and priorities. An alternative approach, which is likely to strengthen collaboration among state departments, is to consider a centralised science and technology vote for all R&D activities across state departments. If such an approach were to be adopted, science councils could report to DST and could take on contract work for other departments.

Second, it is proposed that a national Energy Research and Development Desk be established. This could be managed as a committee under the auspices of the National Advisory Council on Innovation (NACI) or the Academy of Science of South Africa. It would give effect to a formal coordination mechanism (See paragraph above), with representation from relevant state department agencies, science councils and state-owned enterprises, HEIs with an active energy research portfolio and private sector companies with an active energy research portfolio and/or energy intensive operations to coordinate energy and energy-related R&D.

- **Funding:** It is recommended that a more substantial portion of the national R&D vote be allocated to energy and energy-related research in line with national priorities. Research programmes should be driven upon agreement by the relevant state departments and based on advice by the proposed national Energy Research and Development Advisory Desk. It is recommended that at least 1.5% of the fiscal appropriation be earmarked for R&D support, and that a higher proportion of this be earmarked for energy than is currently the case.
- **Human capital development:** It is recommended that human capital development for energy areas aligned with the national energy agenda needs to be prioritised. It is proposed that more research chairs, CoCs and Centres of Excellence (CoEs) be established and funded in line with established funding patterns. CoCs and CoEs have the additional advantage that inter-institutional collaboration is required.

General energy fields related recommendations:

- **Coal:** Based upon the continued use of coal in parallel with the stringent and imminent cap on greenhouse gas emissions, methods to ensure the cleaner use of coal in South Africa are of immediate and paramount importance. Investment in clean coal technologies and carbon capture and storage (CCS) should be increased to provide a solid scientific foundation for a dominating (and expected to be dominating until well beyond 2030) energy source.
- **Gas:** Significant R&D is needed in shale gas, which has the potential to provide a lower carbon medium-term energy future for South Africa. Research is needed to support possible future exploitation of the resource, to support techno-economic evaluations of exploitation pathways, to determine environmental and other risks, risk abatement strategies and beneficiation strategies.
- **Renewable energy:** Significant investment of the R&D effort in renewable energy is needed to meet national targets. The penetration of renewable energy in South Africa should be increased through appropriate mechanisms. A stronger coordination is needed to circumvent fragmentation of R&D efforts. Small-scale, off-grid renewable energy systems, especially for rural areas should also be included as a priority area as this is one sector where South Africa needs to make significant progress in the next few years.
- **Nuclear energy:** The implications of delaying the nuclear decision in terms of the country's capability to support (any part of) the nuclear cycle, have to be evaluated and compared with alternative energy supply options.

- **Energy efficiency:** In spite of energy efficiency measures, such as the energy efficiency and demand side management (EEDSM) programme, the commitment to and adoption of energy efficient measures should be increased, *inter alia* by improving awareness and understanding of energy efficiency and implementing effective incentives for the participation of the energy saving drive. More stringent legislation needs to be implemented to drive energy efficiency together with incentive schemes. Financing needs to be adequately available and incentives need to be optimised.

- **Energy economy and policy:** Comprehensive techno-economic feasibility studies are needed to inform the national energy R&D agenda, as well as the planning and legislative environment needed for effective implementation on a path to lower carbon and energy intensity. The studies should include development of road maps for all relevant energy categories, as well as their linkage to energy storage, targeted energy efficiency programmes, transportation networks, distributed energy networks and regional collaboration for energy supply.

The final recommendation is that a regular reporting system, such as this study attempts, be introduced.

1 Introduction

1.1 Background

The Academy of Science of South Africa (ASSAf) was contracted by the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)* and its partner organisation, the Renewable Energy Centre of Research and Development (RECORD), to undertake an in-depth review of the state of energy research in South Africa. The motivation for the project is to improve the understanding of the energy research landscape in South Africa, in order to support the South African National Energy Development Institute (SANEDI) to fulfil its functions in terms of energy research support and coordination in South Africa.

RECORD is one of the divisions of the Clean Energy Solutions portfolio of SANEDI. SANEDI was established by the National Energy Act (*Act 34 of 2008*) as a successor to the previous South African National Energy Research Institute (Pty) Ltd (SANERI) and the National Energy Efficiency Agency (NEEA). SANEDI's mandate is to serve as a catalyst for sustainable energy innovation, transformation and technology diffusion in support of South Africa's sustainable development.

RECORD is supported by the South African-German Energy Programme (SAGEN), implemented by GIZ. SAGEN promotes investment in renewable energy and energy efficiency and thus supports the development of a sustainable energy sector in South Africa. Under the auspices of SAGEN, GIZ cooperates with SANEDI and RECORD to achieve mutually agreed goals.

1.2 Objective of Study

The objectives of the study are described as follows:

- to provide an overview of current energy research being commissioned (the organisations involved and budgets allocated) and undertaken at South African higher education institutions (HEIs);
- to identify common themes and priorities in energy research;
- to identify possible gaps that are not being covered by current energy research;
- to compile a profile of the energy researchers actively working in the field;
- to make recommendations on future energy research focal areas for South Africa;
- to investigate the budgetary allocation to energy research in South Africa from the National Research Foundation (NRF) and other public and private institutions.

1.3 Strategic Position of the Academy

ASSAf is the only national science academy to be officially recognised by the South African government through the Academy of Science of South Africa Act (*Act 67 of 2001*), as amended in 2011. ASSAf is unique in that it is an independent body, comprising an assembly of top scholars from many disciplines who have shown interest in and capacity for promoting the development of a prosperous and fully enabled society. The Academy thus aims to mobilise the best intellect, expertise and experience to investigate and provide evidence-based solutions to national or regional problems from within or outside its Membership.

ASSAf can be regarded as the 'brains trust' of the nation. The Academy is apolitical, trustworthy and not motivated by profit. Multidisciplinary in nature, the Academy is characterised by scientifically rigorous analyses of evidence, ensuring best practice is achieved and the consensus of diverse experts.

1.4 Study Methodology

A study panel was appointed and approved by the ASSAf Council to undertake the study. The members of the panel, who serve on a voluntary basis, have multidisciplinary backgrounds and were drawn from both the ASSAf Membership, as well as other experts within South Africa (**Table 1.1**). Panel members' biographies are given in Appendix 1.

Table 1.1: Membership of the panel on *The State of Energy Research in South Africa*

Member	Organisation
Prof Frederik van Niekerk (Chair)	North-West University
Prof Wikus van Niekerk	Stellenbosch University
Prof Nelson Ijumba	University of KwaZulu-Natal
Prof Regina Maphanga	University of Limpopo
Dr Steve Lennon	Eskom
Prof Sue Harrison	University of Cape Town

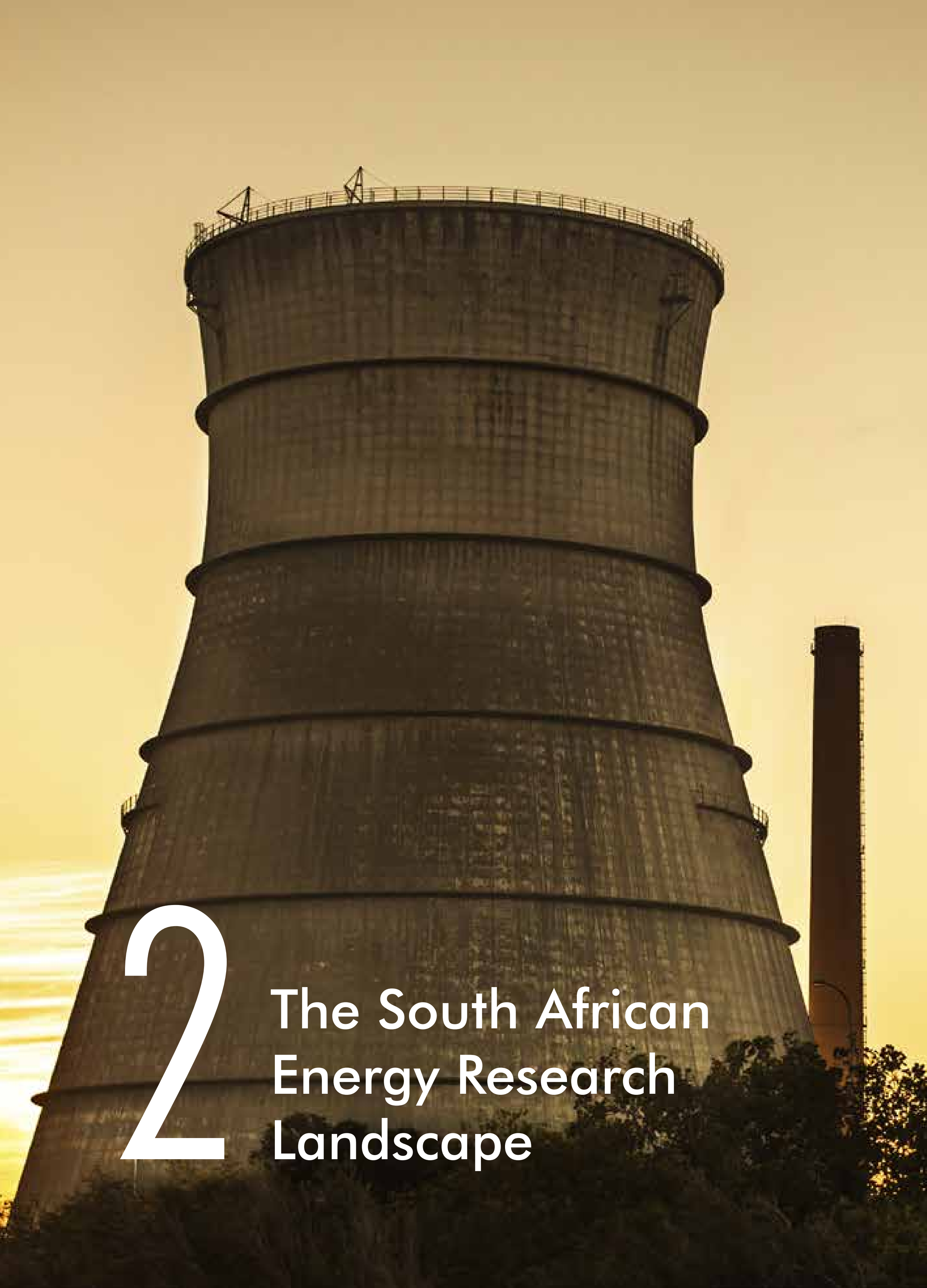
A range of methodologies was selected in order to meet the study brief. These included:

- The study was divided into five broad fields: Renewable Energy (wind, wave, solar, etc.), Renewable Energy (bio-energy), Nuclear Energy, Fossil Fuels, and Energy Efficiency and Storage. Panel members assumed responsibility for various topics and postgraduate students or postdoctoral fellows were appointed to perform desktop studies, to conduct interviews, develop questionnaires, summarise data and write reports, under the supervision and guidance of the panel members. The panel met four times to plan the study, analyse the results, identify gaps and make recommendations.
- Additional activities, not part of the original scope of work requested by the contracting party, were included to complement the study, without the need to change the budget to complete the study.
  - A bibliometric study of energy research in South Africa, covering the specified energy fields, was commissioned. Data were analysed and form an integral part of the study.
  - A scan of energy and energy-related intellectual property (IP) was commissioned. The results form an integral part of the study.
  - A scan of energy and energy-related Masters and doctoral theses/dissertations, with energy or energy-related themes, was undertaken.

1.5 Scope of Project

The study is limited to energy research in South Africa: data on energy research undertaken at HEIs and the private sector were collected through a questionnaire requesting data for the timeframe 2010–2013. This timeframe was selected as although the focus is on current energy research, it was recognised that a slightly broader window would yield a better perspective than a single year of data. The desktop study covers energy production, energy storage, energy efficiency and energy policy. Reticulation and distribution were not included in the study. The social component related to energy research in South Africa was not the primary focus, although information was not explicitly excluded. It is recognised, however, that social and environmental aspects of energy research are important focus areas and that they should be included in a follow-up study of energy research in South Africa.

This is the first such study on energy research in South Africa. It was conducted with a limited budget and in a relatively short timeframe. The report should be regarded as a baseline against which regular updates can be made.



2 The South African Energy Research Landscape

South African energy needs and planning should be expected to dominate local energy R&D funding. The energy planning landscape should be taken into account in assessing the state of energy research in South Africa. In this chapter, four important documents are highlighted in terms of energy planning:

- the Department of Science and Technology (DST) 10-Year Innovation Plan (DST, 2008);
- the Department of Energy (DoE) Integrated Resource Plan (IRP) (DoE, 2013);
- the National Development Plan (NDP) (NPC, 2012);
- the National Energy Act (2008).

The Integrated Energy Plan (IEP) is not included in the above list since it had not been formally approved at the time of publication of this report. The DoE has formally launched the much-anticipated public consultation phase for the formulation of an IEP for South Africa. DoE expects the plan to be published during the course of 2014. A draft Integrated Energy Planning Report was endorsed by Cabinet in July 2013. The publication of an IEP is a requirement of the National Energy Act of 2008.

In Section 2.4, a brief description of the South African National System of Innovation (NSI) is presented. While the documents described above can be seen as outlining the strategy regarding energy in South Africa, we attempt in Section 2.4 to provide a simple schematic of the structures employed in energy and energy-related research. We highlight the Centres, Chairs and other structures for energy and energy-related research.

Before describing the current energy research landscape, a brief historical context of R&D in South Africa is provided.

2.1 The History of Research and Development in South Africa

At least five distinct but overlapping periods can be identified of organised R&D in South Africa's modern history, in terms of the role that science and engineering were expected to play with respect to, initially, colonial objectives and, later, national objectives.

The first period was driven by the interests of European scientists, based on the twin benefits of a southern scientific location and a relatively developed local society and economy. It was the astronomical attraction of the southern skies that led the first internationally recognised scientist, Abbe Nicolas Louis de la Caille, to spend time in South Africa. Two generations later, in 1820, the first scientific institution, namely the Royal Observatory, was established in South Africa. Its main purpose was to assist with marine navigation, but it also pioneered a geodetic survey of southern Africa, thus laying the groundwork for future minerals exploration.

The second period, dating from a decade or two before Union (1910) until the 1930s, was focused on utilising research and scientific knowledge to unlock southern Africa's natural resources potential in minerals and agriculture. This strategy saw the establishment of facilities such as the Onderstepoort Veterinary Research Institute, the Geological Survey of the Union of South Africa and the Government Minerals Laboratory. The fairly rapid establishment of a range of agricultural, marine and forestry research bodies followed.

World War I exposed the vulnerability of countries that were too dependent on primary industries, ushering in a third period of research development. In particular, there was a new and urgent focus on manufacturing, given that supply chains were stretched to their limits by the conditions of war. After World War I, Eskom, Iscor, and the Industrial Development Corporation were established. After World War II, the Council for Scientific and Industrial Research (CSIR) was established. Later, other science councils, such as Mintek, the South African Bureau of Standards and the Medical Research Council (MRC) were spun off from the CSIR to function independently.

Although the Atomic Energy Board was established in 1948 and Sasol in 1950, these parastatals in energy research really came of age in the next period, which supported the consolidation of apartheid from the 1960s until the advent of democracy in the 1990s. The three pillars of energy security, food security and military dominance of the subcontinent dominated investment into the National System of Innovation (NSI) during this period. Very difficult technological problems had to be solved locally because of a range of sanctions imposed, and this was done successfully. Broader energy research was conducted at the CSIR and funded by means of a coal levy. Soekor was established by the State to conduct oil and gas exploration. An overcapacity in electrical power generation was created by Eskom, providing significant work over two decades for the local construction industry. The impact of this period of high investment in scientific research and technological development cannot be underestimated. The South African NSI was taken to a much higher level quite rapidly.

The challenge facing science and technology policymakers in the fifth and current period, after 1994, was to move smoothly into a globalising world from a position of severe isolation, with a diminished investment commitment from government, given other urgent priorities. Given that the majority of the population could now vote, the focus in research shifted towards research that paid a higher social dividend. State support for the MRC, for example, rose significantly in the years immediately following 1994. The coal levy was done away with, which had the knock-on effect of reducing energy research at Enertek, the energy research division of the CSIR. Government's response was to establish SANERI by an Act of Parliament, but SANERI has not been funded at the same level as Enertek was, and does not incorporate the R&D activities of Eskom.

The independent mindset that developed as a response to sanctions is still fairly prevalent in sections of South Africa's research community and even in government. A better response to the challenges faced in a competitive, more open world is to ask three questions when developing a research strategy:

1. What gaps need to be filled that cannot or should not be filled by importing knowledge or technology?
2. Where can South African R&D be excellent? Human palaeontology is an example here.
3. Are there local advantages that South Africa offers that will attract international science and associated investment? Astronomy is an example here.

Energy R&D needs to be subjected to these questions too.

2.2 DST 10-Year Innovation Plan

The DST 10-Year Innovation Plan (DST, 2008) identifies energy security as one of five Grand Challenges for science and innovation in South Africa.

The three principal global energy challenges identified are:

- the need for energy security as supply and security concerns converge;
- protecting the environment, particularly given high levels of fossil fuel emissions;
- access by the developing world to affordable, safe, clean and reliable energy.

The 10-Year Innovation Plan called for an increased energy supply infrastructure to ensure accelerated and sustainable growth and prioritised long-term energy supply infrastructure planning, including a more structured planning relationship between government and the private sector. In 2010, the 10-Year Innovation Plan forecast an electricity demand of about 60 000 MW by 2018 and 90 000 MW by 2022. (The IRP has in the meantime provided a more refined forecast of the needs, based on more recent data.) In the 10-Year Innovation Plan, a possible electricity generation profile for 2018 was presented, given the above policy drivers and projections and the energy context at the time of publication (**Figure 2.1**). There have been fairly substantial changes to this projected profile in recent policy documents, chiefly in the envisaged contribution from nuclear energy.

Coal and gas including large hydro (50 000 MW)	Nuclear equivalent to > 4 x Koeberg capacity (8 000 MW)	Renewable energy sources (2 000 MW)	Energy generation sources
Clean coal technologies Carbon capture and sequestration	3rd generation reactors Pebble-bed Modular Reactor	Solar, hydro, wind, ocean/wave, biomass and waste	Technologies for cultivating energy sources
Eskom, Sasol, PetroSA, CEF/SANERI and universities	Eskom, Necsa, PBMR, IST Nuclear and universities	Eskom, CEF, Sasol, independent producers, SANERI and universities	Research organs in the NSI
Electricity Liquid fuels Cooking and heating	Electricity Process heat Hydrogen	Electricity Biofuels Hydrogen	End uses

Figure 2.1: A possible South African energy matrix, 2018 (DST, 2008)

The 10-Year Innovation Plan identified a number of energy-related major R&D thrusts:

Clean coal technologies

Given the fact that coal is South Africa's primary energy source, coal is abundant enough to ensure security of supply in future. Adoption of clean coal technologies could significantly reduce the country's carbon footprint, both in producing electricity, as well as in the production of transportation fuels.

The 10-Year Innovation Plan calls for SANERI[1], Eskom, Sasol and various Central Energy Fund (CEF) subsidiaries to work together to advance clean coal technologies. South Africa's competitive edge in cheap electricity and coal-to-liquid technology is dependent on reducing the environmental footprint of processing coal.

Nuclear energy revisited

In 2008, the 10-Year Innovation Plan presented nuclear energy as a major/significant future energy option for South Africa, and the Pebble-bed Modular Reactor (PBMR) was strongly supported by government. However, in February 2010, Finance Minister Pravin Gordhan announced that the South African government would stop funding the development of a demonstration power plant for the PBMR.

South Africa's PBMR was an advanced Generation IV reactor. The 10-Year Innovation Plan stated the need for South Africa to strengthen the innovation chain in nuclear energy science. Planning and coordination of R&D to support conventional reactors in materials, safety, waste, reactor physics, etc. was called for, as well as a localisation programme to include knowledge-transfer systems, enabling the development of local expertise to meet the industrialisation agenda.

Embracing renewable energy technologies

In line with international trends, South Africa is to pursue renewable energy technologies actively to be included in its future energy blend. There is a special focus on solar energy.

1 The South African National Energy Development Institute (SANEDI) is a Schedule 3A state-owned entity that was established as a successor to the previously created South African National Energy Research Institute (SANERI) and the National Energy Efficiency Agency (NEEA). The main function of SANEDI is to direct, monitor and conduct applied energy research and development, demonstration and deployment, as well to undertake specific measures to promote the uptake of green energy and energy efficiency in South Africa.

The promise of hydrogen

The 10-Year Innovation Plan identified the importance of hydrogen and hydrogen-related science and technology (S&T) as a future growth area. Given the importance of platinum group metals (PGMs) in fuel cells and electrolysers, and given the abundance of PGMs in South Africa, this is also earmarked as a major future growth area in terms of economic development.

The Grand Challenge outcomes (DST, 2008) required that by 2018, South Africa should have:

- *"Expanded the energy supply infrastructure, with 80 percent of new capacity coming from clean coal technologies and nuclear plants;*
- *10 percent of energy used coming from renewable sources, 20 percent from nuclear and 70 percent from coal (of which 30 percent would be based on clean coal technologies);*
- *Expanded the knowledge base for building nuclear reactors and coal plants parts; source more than 50 percent of all new capacity locally;*
- *Successfully integrated uranium enrichment into the fuel cycle and feeding into the commercial reactors;*
- *A well-articulated energy efficiency programme and per capita energy demand reduced by 30 percent;*
- *A 25 percent share of the global hydrogen infrastructure and fuel cell market with novel PGM catalysts; and*
- *Have demonstrated, at pilot-scale, the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source."*

2.3 Integrated Resource Plan

The Integrated Resource Plan (IRP) is a scenario-based plan which outlines the medium and long-term electricity planning requirements in South Africa (DoE, 2010). In **Figure 2.2**, new generation capacity in the Revised Balanced Scenario is presented. The latest IRP update (DoE, 2013) takes into account the economic growth suggested by the NDP in order to reduce unemployment and alleviate poverty in South Africa. The average growth rate (taken as 5.4% per year until 2030) is also aligned with a shift in economic development away from energy intensive industries. The total installed capacity in 2030 is now projected to be reduced from 67 800 MW to 61 200 MW.

An alternative to a fixed capacity plan (as espoused in the IRP 2010) is a more flexible scenario-based approach, which is necessitated by uncertainty regarding the future energy demand, the potential for shale gas, the extent of other gas developments in the region, the global agenda to combat climate change and the resulting mitigation requirements on South Africa, as well as the uncertainty in the cost of nuclear capacity and future fuel costs (specifically coal and gas), including fuel availability.

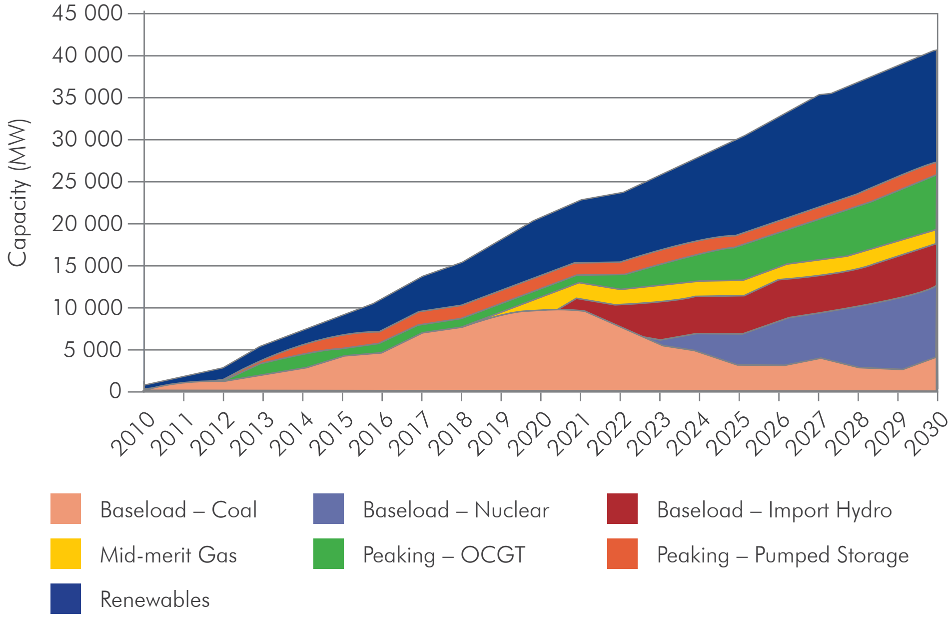


Figure 2.2: Revised Balanced Scenario for new generation capacity (DoE, 2010)

In order to achieve this flexibility, a number of decision points have been identified in the updated IRP. These include:

- A possible delay in the nuclear decision until after 2025 or even 2035, by exploring alternative options, such as regional hydro and further exploration of the shale gas potential.
- Procurement of a new set of fluidised-bed combustion coal generation should be launched for a total of 1 000 to 1 500 MW capacity.
- Exploring regional hydro projects in Mozambique and Zambia and other regional coal options.
- Pursuing regional and domestic gas options and stepping up shale exploration.
- Continuation of the current renewable energy bid programme with additional annual rounds of 1 000 MW photovoltaic (PV) capacity, 1 000 MW wind capacity and 200 MW concentrated solar power (CSP) capacity, with the potential for hydro at competitive rates.
- Developing small-scale distributed generation options.
- Plant life extension programmes with concomitant environmental compliance modifications, compared to new coal-fired generation which is more efficient and with lower emission rates, or non-emitting alternatives under more aggressive climate change mitigation objectives.

2.4 National Development Plan and Energy

The NDP is "… *a plan for the country to eliminate poverty and reduce inequality by 2030 through uniting South Africans, unleashing the energies of its citizens, growing an inclusive economy, building capabilities, enhancing the capability of the state and leaders working together to solve complex problems…*" (NPC, 2012). The NDP was developed by the National Planning Commission (NPC), a commission established by the Presidency consisting largely of people from outside government, with a mandate to be critical, objective and cross-cutting. The NDP has been endorsed by government.

The NDP recognises a changing global economy and the need for increased regional cooperation through exploiting complementary national endowments for mutually beneficial cooperation, such as investing in and helping to exploit the wide range of opportunities for low-carbon energy from hydroelectric and other clean energy sources in southern Africa.

The production of sufficient energy to support industry at competitive prices, ensuring access for poor households, while reducing carbon emissions per unit of power by about one-third, is identified as an enabling milestone by 2030.

Another key enabling milestone identified in the plan is environmental sustainability and resilience. The plan requires achievement of the peak, plateau and decline trajectory for greenhouse gas (GHG) emissions, with the peak being reached around 2025. An economy-wide carbon price and zero emission building standards should be entrenched by 2030. The plan requires absolute reductions in the total volume of waste disposed to landfill each year and sets as a requirement the production of at least 20 000 MW of energy from renewable sources by 2030.

In the transport sector, the emphasis will be on increasing energy efficiency and the resilience of transport networks, drawing on progress in establishing renewable energy resources.

The NDP identifies innovation and technology for cleaner coal use as key drivers for achieving a greener energy dispensation by 2030. The plan identifies:

- **Gas as an alternative to coal** to reduce South Africa's carbon intensity and GHG emissions. Identified possibilities include off-shore natural gas, coalbed methane, shale gas resources in the Karoo Basin and imports of liquefied natural gas, which could be used for power production, gas-to-liquids refineries and other industries.
- **Off-shore natural gas** discovered off the West Coast for power production.
- **Coalbed methane gas** and underground coal gasification technology is also being developed.
- **Technically recoverable shale gas** in South Africa, estimated to form the fifth largest reserve globally (US EIA, 2012). Confirmation through further drilling of test wells is needed. Shale gas as a transitional fuel has the potential to contribute a very large proportion of South Africa's electricity needs.
- **Liquefied natural gas** (increasingly delinked from oil prices) may allow South Africa to diversify its energy mix and presents economic and environmentally positive options for power production, gas-to-liquids production (at Mossgas) and other industrial energy uses.

Within the NDP, short, medium and long-term priorities are proposed in terms of the planning of energy and energy developments in South Africa (NPC, 2012). These are summarised below.

Short term

Over the next five years, priorities are, *inter alia*, to:

- Develop a national coal policy and investment strategy and, in partnership with coal industry leaders, reach an agreement to secure coal for domestic energy production needs.
- Invest in new and existing freight rail infrastructure for the transport of coal.
- Promote exploration of coal seam and shale gas reserves, the development of off-shore gas and investment in liquefied natural gas landing infrastructure.

- Commission Eskom's Medupi coal power station and Ingula pumped-storage plant, as well as a minimum of 3 725 MW of renewable energy from the private sector.
- Undertake various policy amendments to improve efficiencies and introduce new legislation (Independent System and Market Operator Act) to create an independent state-owned enterprise to take over some of Eskom's functions.
- Focus on resolving maintenance and refurbishment backlogs, and human capital needs in the 12 largest municipalities, representing 80% of municipal electricity distribution.
- Develop a sustainable national electrification plan.
- Further investigate the implications of greater nuclear energy use, particularly costs and financing mechanisms.
- Agree on a funding mechanism for upgrading of existing refineries to ensure that they are able to comply with new fuel quality standards.
- Address GHG emissions from the transport sector by introducing a vehicle point-of-sale carbon tax and encouraging greater use of hybrid or electric vehicles and public transport.

Medium term

By 2020, goals are that:

- Coal rail capacity will be adequate for planned coal export port capacity at Richards Bay (at least 91 million tons per year).
- The Kusile coal-fired power station will be operational and at least 7 000 MW of renewable energy supply will be in place, predominantly from independent power producers (IPPs).
- Liquefied natural gas infrastructure will be installed and ready to supply the first combined cycle gas turbines.
- Pro-poor electricity tariffs will be better targeted to include all qualifying electricity customers.
- At least 85% of the population will have access to grid electricity.
- A decision on the status of petroleum products, specifically whether to invest in a new refinery to continue relying on imports, will be made.

Long term

By 2030:

- More than 20 000 MW of renewable energy will be contracted.
- Rail and port capacity will be further developed to support increased coal exports.
- Older coal-fired power stations will be decommissioned (about 11 000 MW) and new coal-fired power stations (about 6 000 MW) commissioned, dependent on South Africa's international climate change commitments.
- R&D and technology-transfer agreements relating to cleaner coal technologies will be promoted.
- There will be a full understanding of the extent of economically recoverable coalbed seam and shale gas reserves, and subject to acceptable environmental controls, they will be exploited for power production.
- The energy sector will be on a path towards lower carbon and energy intensity.
- At least 90% of the South African population will have access to grid electricity.
- Hybrid and electric vehicles will be more widely used.

2.5 National Energy Act

The National Energy Act *(Act 34 of 2008)* sets out the core aspects of the DoE mandate. These are to:

- ensure that diverse energy resources are available in sustainable quantities and at affordable prices in the South African economy to support economic growth and poverty alleviation, while also taking into account environmental considerations;
- plan for the increased generation and consumption of renewable energy, and contingency energy supply;
- hold the strategic energy feedstock and carriers, adequate investment in appropriate upkeep, and access to energy infrastructure;
- collect data and information regarding energy demand, supply and generation;
- promote the efficient generation and consumption of energy, electricity regulation and energy research.

In terms of its policy mandates, the department is working with a range of documents and legislation which support the long-term vision for South Africa to use as much renewable energy as possible; create the necessary conditions for the introduction of an independent systems operator and IPPs; and position South Africa to become globally competitive in the use of innovative technology for the design, manufacture and deployment of state-of-the-art nuclear energy systems, power reactors, and nuclear fuel cycle systems (DoE, 2008).

The DoE strategic goals (DoE, 2011) over the medium term are to:

- ensure that energy supply is secure and demand is well managed;
- facilitate an efficient, competitive and responsive energy infrastructure network;
- ensure that there is improved energy regulation and competition;
- ensure that there is an efficient and diverse energy mix for universal access within a transformed energy sector;
- ensure that environmental assets and natural resources are protected and continually enhanced by cleaner energy technologies;
- implement policies that adapt to and mitigate the effects of climate change;
- implement good corporate governance for effective and efficient service delivery.

SANEDI was established in terms of the National Energy Act *(Act 34 of 2008)*. The functions of SANEDI include:

"(a) energy efficiency:

i. undertake energy efficiency measures as directed by the Minister;
ii. increase energy efficiency throughout the economy;
iii. increase the gross domestic product per unit of energy consumed; and
iv. optimise the utilisation of finite energy resources;

(b) energy research and development:

i. direct, monitor, conduct and implement energy research and technology development in all fields of energy, other than nuclear energy;

ii. promote energy research and technology innovation;

iii. provide for:

(aa) training and development in the field of energy research and technology development;

(bb) establishment and expansion of industries in the field of energy; and

(cc) commercialisation of energy technologies resulting from energy R&D programmes;

iv. register patents and intellectual property in its name resulting from its activities;

v. issue licences to other persons for the use of its patents and intellectual property;

vi. publish information concerning its objects and functions;

vii. establish facilities for the collection and dissemination of information in connection with research, development and innovation;

viii. undertake any other energy technology development related activity as directed by the Minister, with the concurrence of the Minister of Science and Technology;

ix. promote relevant energy research through cooperation with any entity, institution or person equipped with the relevant skills and expertise within and outside the Republic;

x. make grants to educational and scientific institutions in aid of research by their staff or for the establishment of facilities for such research;

xi. promote the training of research workers by granting bursaries or grants-in-aid for research;

xii. undertake the investigations or research that the Minister, after consultation with the Minister of Science and Technology, may assign to it; and

xiii. advise the Minister and the Minister of Science and Technology on research in the field of energy technology." (DoE, 2008)

2.6 The National System of Innovation

The triple-helix phenomenon (Etzkowitz, 2000), i.e. the relationships among universities, industry and government, significantly influences the growth of the innovation landscape in South Africa. The contribution of these stakeholders will vary depending on the innovation and its contribution to national and continental imperatives. Currently the triple-helix model is not optimally used in South Africa, as linkages among universities, industry and government are sub-optimal (DVC Forum, 2011).

A simplified depiction of the triple-helix role players is presented in **Figure 2.3**. Universities are categorised into three groups, i.e. classical universities, comprehensive institutions (in which a classical university and a technikon have merged) and universities of technology. While it may be an oversimplified distinction, universities are mainly regarded as focusing on basic and applied research, whereas universities of technology, due to their developmental history, are concerned mainly with technical applications. In addition, mechanisms introduced by the DST, with the aim of furthering the two research regimes are presented: Centres of Excellence (CoEs) as managed by the NRF are intended to strengthen knowledge creation through basic research and Centres of Competence (CoCs) are seen as instruments designed to assist in crossing the innovation chasm. Another form of CoEs, introduced by the Department of Trade and Industry (the dti), focuses on pre-commercial incubation and demonstration.

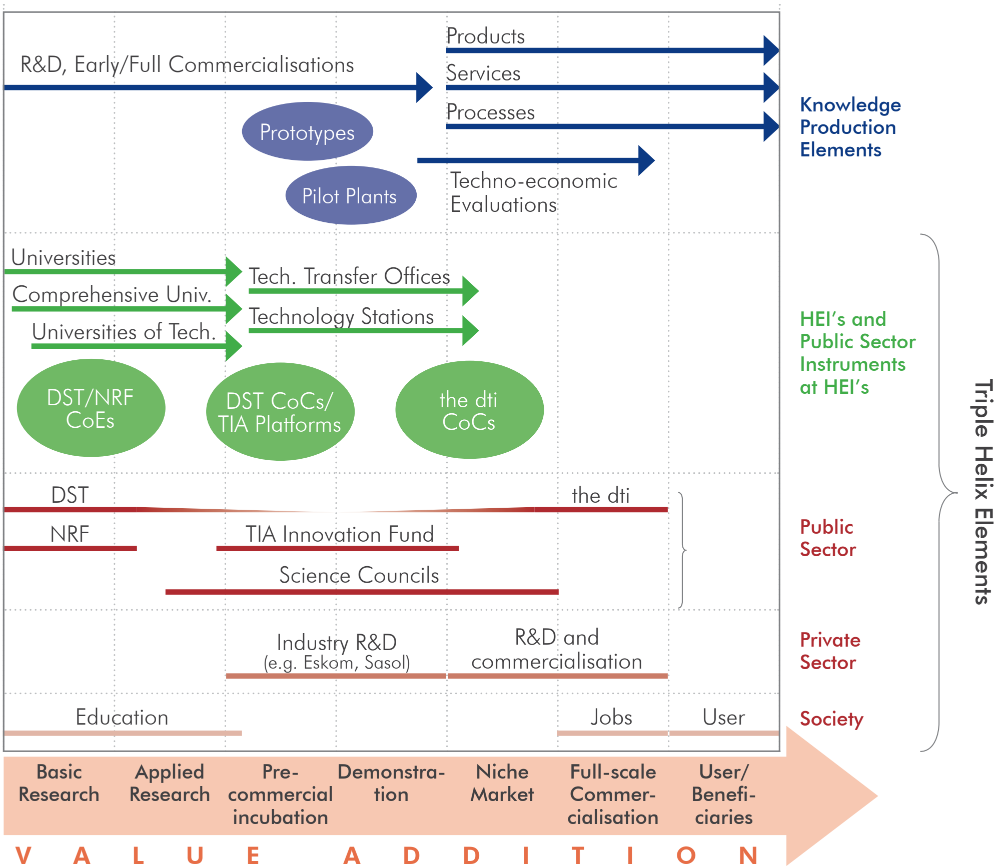


Figure 2.3: A value addition landscape for a NSI supporting a knowledge economy (DVC Forum, 2011)

With the emphasis of broadening the scope of HEIs, and out of the necessity to earn third-stream revenue, universities have started to develop Technology Transfer Offices. These are mainly concerned with the identification of business opportunities and the protection of intellectual property rights. They are lacking in experience of commercialisation. The DST and some international partners started the Technology Stations Programme (later called Tshumisano) to transfer technology and knowledge to small, medium and micro enterprises (SMMEs) in identified industry sectors. The inclusion of these two types of structures within a higher education environment was recognised as an ideal pathway for HEIs to venture into the innovation chasm, although the need to cultivate such an environment was emphasised if they were to operate optimally (DVC Forum, 2011).

The following energy or energy-related R&D centres/institutes have been established at HEIs:

DST/NRF chairs in energy or energy-related research:

NWU[2] : Research Chair: Biofuels and Other Clean Alternative Fuels

NWU: Nuclear Engineering

SU: Biofuels and Other Clean Alternative Fuels

SU: SANERI Chair of Energy Research

UWC: NanoElectrochemistry and Sensor Technology

Wits: Clean Coal Technologies

TUT: Energy Production and Consumption for Sustainable Global Survival

DST programme in renewable energy or energy-related research:

SU: Centre for Renewable and Sustainable Energy Studies (CRSES)

DST Centres of Competence (CoCs):

NWU and CSIR: Hydrogen South Africa (HySA) infrastructure for innovation in hydrogen production, infrastructure, codes and standards

UCT and MINTEK: HySA catalysis for innovation in fuel cell catalysis

UWC: HySA systems for innovation in fuel cell systems

The following centres/chairs for energy and energy-related research and innovation, established by HEIs can be identified:

UCT: Energy Research Centre (ERC) – Energy Policy, Climate Change, Modelling

NWU: Unit for Energy Systems

UP: UP launched an Energy Cluster in 2013, Energy Hub in Energy Efficiency

UWC: South African Institute for Advanced Materials Chemistry

CSIR: Battery Research Unit in the Material Sciences Division

CPUT: South African Renewable Energy Technology Centre

Eskom Power Plant Engineering Institute (EPPEI)

The Eskom Power Plant Engineering Institute (EPPEI) is a new organisation within Eskom that serves to increase the level of education and skills available in a few major specialised technical areas. Each area of specialisation was defined on the basis of the current and future needs of Eskom. The main focus area for each specialisation is defined by the Eskom corporate specialists. A preliminary list of focus areas was defined during a workshop held at the Eskom Academy of Learning on 11 July 2011 and has been updated due to the contributions of the Eskom Research and Development Department. Chairs funded by Eskom are listed in **Table 2.1**.

2 Abbreviations of institutions used are as follows:

CPUT: Cape Peninsula University of Technology
CSIR: Council for Scientific and Industrial Research
NWU: North-West University
SU: Stellenbosch University
TUT: Tshwane University of Technology
UCT: University of Cape Town
UKZN: University of KwaZulu-Natal
UP: University of Pretoria
UWC: University of the Western Cape
Wits: University of the Witwatersrand

Table 2.1: Specialist Chairs funded by Eskom and the lead university

Specialist Chairs:	Lead university:
Combustion Engineering	Wits
Emission Control Technologies	NWU
Materials Engineering	UCT
Plant Asset Management	UP
Energy Efficiency	UCT
Renewable Energy Technologies	SU
High Voltage Engineering (AC)	Wits
High Voltage Engineering (DC)	UKZN

2.7 Energy and Energy-related Research Expenditure

2.7.1 National Survey of Research and Experimental Development

The 2011/12 National Survey of Research and Experimental Development shows the gross expenditure on research and development (GERD), all categories, as indicated in **Figure 2.4** (in constant 2005 rand values) and **Figure 2.5** (as a % of the gross domestic product (GDP)) for 1991/92 (HSRC, 2014).

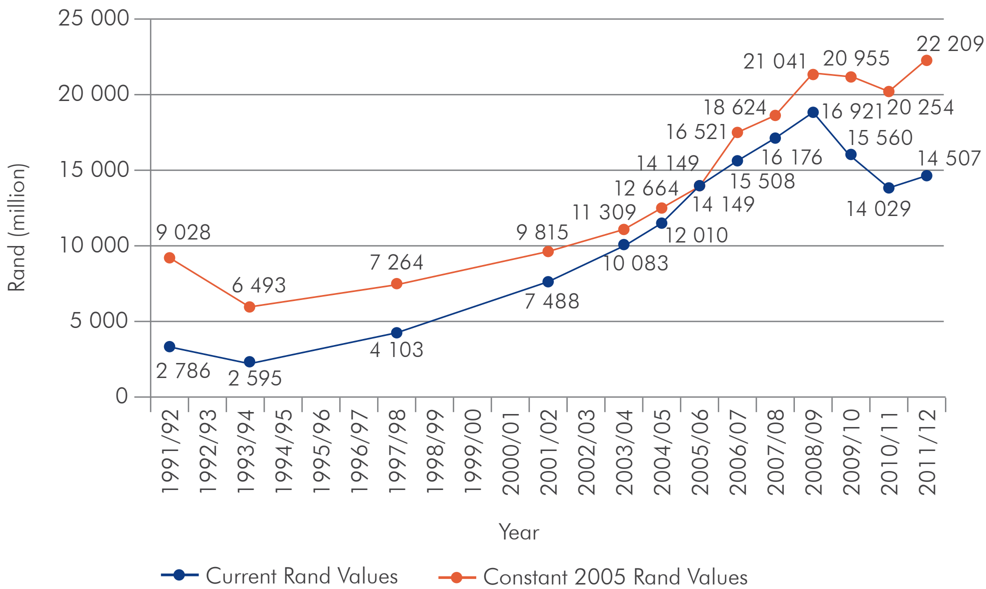


Figure 2.4: GERD in current and constant 2005 rand values, 1993/94–2011/12 (HSRC, 2014)

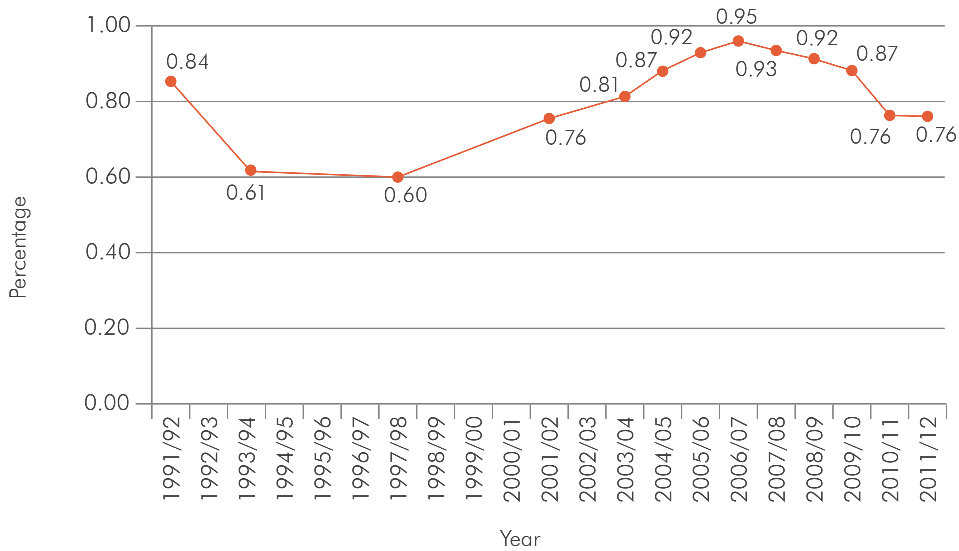


Figure 2.5: GERD as a percentage of GDP, 1991/92–2011/12 (HSRC, 2014)

The 2010/11 National Survey of Research and Experimental Development (HSRC, 2013) shows that South Africa spent R898.2 million as GERD on energy, which amounts to 4.4% of the total GERD of R22.4 billion. This report indicates a decline of R49.4 million (-5.2%) from the R947.5 million of 2009/10. However, the compound annual growth rate (CAGR) on expenditure on R&D on energy from 2001/02 until 2010/11 is 11.7%. The analysis from the R&D survey report shows that even though expenditure on R&D in the energy sector has increased with CAGR of 11.7% over the past nine years, the expenditure has decreased in the past five years since 2008/09, due to a number of factors, including the impact of the economic climate since 2008/09, the closure of the PBMR, etc. Departments with an energy budget (including DST, DoE, the dti, and the Department of Public Enterprises (DPE)) need to work closely together to ensure that the efforts of R&D in the energy sector are adequately supported to support the country's needs on energy.

The 2012/13 National Surveys of Research and Experimental Development were not released at the time of finalising this report.

2.7.2 Department of Science and Technology

The aim of the S&T Budget Vote is to realise the full potential of S&T in social and economic development by developing human resources, research and innovation. The DST executes its mandate through the implementation of the 1996 White Paper on Science and Technology, the National Research and Development Strategy and the 10-Year Innovation Plan. The plan aims to make S&T a driving force in enhancing productivity, economic growth and socio-economic development (National Treasury, 2013a).

The DST Research, Development and Innovation Objectives (Programme 2) call for, *inter alia*, an increase in the number of R&D initiatives in biosciences, hydrogen and energy-related fields from six initiatives in 2012/13 to 14 initiatives in 2015/16.

The *DST Hydrogen and Energy Programme* provides policy direction in the long term and cross-cutting research, development and innovation in the energy sector. This entails playing a key role in developing a sustainable and globally competitive South African energy knowledge base and industry that will ensure broader socio-economic benefits for the country from the global hydrogen economy. Bursaries are also funded through the NRF. The department describes its priority agenda in terms of Grand Challenges, of which energy security is one. In 2012/13, R130.8 million was spent on transfers and subsidies for the energy security Grand Challenge and the hydrogen strategy. Over the medium term, the focus will be on implementing the hydrogen strategy through the three established CoCs to facilitate human capacity development, research and the commercialisation of companies.

The 2012/13 Annual Report of DST indicates the following earmarked funding for energy or energy-related research (**Table 2.2**).

Table 2.2: Distribution of DST funding for energy or energy-related research

DST energy budget 2012/2013 (R million)		
Energy Security Grand Challenge	39.0	Support R&D in the renewable energy sector
Hydrogen Strategy (Capital)	54.5	Support research infrastructure in the hydrogen and energy sector
Hydrogen Strategy (Operational)	30.7	Support R&D in the hydrogen and energy sector
Other	6.7	

Note: These programmes are currently managed by DST directly.

The NRF and the Technology Innovation Agency (TIA) are two important organisations supported by DST to realise the full potential of S&T in social and economic development by developing human resources, research and innovation. The research centres and chairs supported by DST are listed in the previous section.

Technology Innovation Agency

TIA supports the development and commercialisation of competitive technology-based services and products. TIA's expenditure on projects is listed in **Table 2.3**.

Table 2.3: TIA expenditure on projects, 2012/13

	2012/13 (R million)	2012/13 (R million)	2012/13 (R million)
Project Funding	300.9	179.9	275.1
Ring-fenced Projects (lodged by DST)	24.1	43.2	41.8

During 2012/13, TIA supported the development of 55 products, processes and services, of which 10% fell within the energy sector.

TIA energy research expenditures:

- Renewable energy (alternative transportation, solar thermal energy, wind energy, PV systems, hydro energy)
  - 2012: ≈ R17.1 million
  - 2013: ≈ R20.7 million

- Bio-energy (microalgae to energy, biodiesel, waste to energy)
  - 2011: ≈ R5.2 million
  - 2012: ≈ R7.4 million
  - 2013: ≈ R5.5 million
- Energy safety (energy management)
  - 2012: ≈ R706 000
  - 2013: ≈ R398 000

2.7.3 Department of Energy

The aim of the Budget Vote for the DoE is to formulate energy policies, regulatory frameworks and legislation, and oversee their implementation "to ensure energy security", promotion of environmentally friendly energy carriers and "*access to affordable and reliable energy by all South Africans*" (National Treasury, 2013b). This is accomplished by developing an integrated energy plan, regulating the energy industries, and encouraging electric power investment in agreement with the IRP.

2.7.3.1 Clean Energy Programme

The expenditure distribution to components of the Clean Energy Programme by the DoE is provided in **Table 2.4**.

Table 2.4: DoE expenditure estimates on clean energy

	Audited outcome (R million)			Medium-term expenditure estimate (R million)
	2009/10	2010/11	2011/12	2013/14
Energy Efficiency	253.4	339.3	418.8	1 478.3
Renewable Energy	10.3	25.8	73.6	140.8
Climate Change and Designated National Authority	2.8	2.9	3.3	4.5
Total	**266.4**	**368.0**	**495.7**	**1 623.6**

Expenditure trends

The medium-term spending focus in the clean energy programme will be on increasing transfer payments to SANEDI. These funds will be used to carry out R&D for carbon capture and storage (CCS) and hydraulic fracturing, as well as to conduct a CCS test injection in 2016.

A projected decrease in the medium-term expenditure can be ascribed mainly to a decrease in the national energy efficiency and demand side management grant given to Eskom for installation of solar water geysers (2012/13 – R820.6 million; 2015/16 – R700 million) due to scheduled programme completion (National Treasury, 2013b).

An increase was seen in the expenditure in the Energy Efficiency sub-programme between 2009/10 and 2012/13 due to the introduction and addition of allocations to energy efficiency and demand side management programme implemented by Eskom and selected municipalities, as well as money spent on the solar water geyser programme.

Transfer payments to SANEDI were initiated in 2011/12, with the initial allocation of R20.1 million and increasing to R56.1 million in 2012/13. Under the Renewable Energy sub-programme, SANEDI will receive a total of R386.1 million over the medium term (2013/14: R134.3 million, 2014/15: R162.7 million, 2015/16: R89.1 million). An additional R217 million over the medium term is awarded for R&D into the CCS and hydraulic fracturing projects. Expenditure in the Renewable Energy sub-programme showed a considerable increase between 2009/10 and 2012/13 due to the increase in transfer payments to SANEDI in order to fund its operations and to fund activities in the Working for Energy project.

Renewable energy work has mainly been undertaken through donor funding; for example, the development of the Wind Atlas, wind energy awareness campaign, solar water heating framework, etc. In general, work done is meant to aid implementation rather than pure research.

2.7.3.2 Nuclear Energy Programme

Table 2.5 lists the expenditures by the DoE within the Nuclear Energy Programme.

Table 2.5: Expenditure estimates of the Nuclear Energy Programme

Sub-programme	Audited outcome (R million)			Medium-term expenditure estimate (R million)
	2009/10	2010/11	2011/12	2013/14
Nuclear Safety and Technology	601.0	607.3	638.0	693.3
Nuclear Non-proliferation and Radiation Security	2.2	2.6	0.5	7.9
Nuclear Policy	6.6	2.5	3.8	8.8
Total	**609.9**	**612.3**	**642.3**	**710.0**

Expenditure trends

An increase in expenditure over the medium term in the Nuclear Safety and Technology sub-programme is projected for the establishment of the National Radioactive Waste Disposal Institute in 2013/14.

The majority of spending in the Nuclear Energy Programme is towards transfers made to the nuclear departmental agencies, such as the South African Nuclear Energy Corporation (Necsa) and the National Nuclear Regulator (NNR). During 2013/14, Necsa received a once-off allocation of R33.5 million used towards R&D facilities attached to the SAFARI-1 nuclear reactor, as well as an additional R14.2 million allocated to build the waste processing facility. Over the medium term, the NNR received R116.9 million, with a once-off allocation of R17 million to provide for the emergency preparedness centre and the upgrade of an information and communications technology infrastructure.

Spending between 2009/10 and 2012/13 increased considerably due to the once-off allocation during 2012/13 towards research in preparation for the nuclear build. However, over the medium term, these expenditures are expected to decrease due to a decline in planning required for the nuclear build.

Reductions of R40.3 million are planned over the medium term, which is directed towards the transfer of funds to the aforementioned nuclear departmental agencies.

3 Desktop Study

3.1 Introduction

A desktop study was performed as described in Sections 1.4 and 1.5. Information was gathered using internet searches, interviews and questionnaires. The questionnaire is included in Appendix 2, questionnaire response statistics in Appendix 3 and summaries of the results in tabular form in a separate database provided to *GIZ*. Information was gathered, *inter alia*, on the following fields: Institution, Institution Type, Energy Sector, Key Collaborators, Resources/Infrastructure, Outputs, Funding Received, Funding Institution, Expenditure, Summary of Research Activities, Barriers to Research, Requirements/Needs, Future Plans, and Recommendations for Future Focal Areas.

Table 3.1 summarises research activities reported by participating institutions, by field and sub-field.[3]

The sections that follow highlight the findings that emerged from the desktop surveys and capture the key suggestions made by the respondents. Questionnaires were distributed to 23 HEIs in South Africa and responses were received from 21 HEIs. Of these, 18 HEIs with energy or energy-related research programmes provided input on their programmes. Responses were also received from public institutions: Agricultural Research Council (ARC), CSIR, Eskom, SANEDI, TIA and private companies: South African Sugar Association (SASA) and Sasol. Research activities were reported in energy fields and sub-fields as listed above. In each of the sections below, the following fields from the database are included: institution, sub-field of research, key collaborators, output, as well as funding information, as reported.

The findings in this chapter are based on the responses received from participating institutions; responses that were not received are indicated as such in the tables.

3 A dot indicates reported activity; duplications or related fields have not been removed (e.g. Biogas, Biofuel, Bioethanol). Activities vary greatly in terms of resource investment, duration and impact.

Table 3.1: Research activities reported by participating institutions, by field and sub-field[4]

Institution	Academic	Public	Private	Bio-energy													Renewable Energy (Non-Bio)					Nuclear
				Biogas	Microalgae	Bioethanol	Biobutanol	Biofuel	Bio-paraffin	Biodiesel	Bio-oil	Microbial fuel cells	Food crops to energy	Non-food crops to energy	Biomass	Waste to Energy	Ocean	Wind	Photovoltaic	Solar thermal	Solar water heaters	Nuclear
ARC		•		•						•			•									
CSIR		•	•	•	•	•		•		•												
CUT	•																	•	•	•		
DUT	•			•	•					•						•						
Eskom		•			•										•		•	•	•	•		
MUT	•			•	•	•				•						•						
Necsa		•																				•
NMMU	•				•						•							•		•		
NWU	•			•	•	•	•		•	•	•			•		•						•
RU	•			•	•					•		•		•		•						
SANEDI		•			•											•	•	•	•	•		
SASA			•			•								•								
Sasol			•											•				•	•	•		
SU	•			•	•	•		•		•			•	•			•	•		•		
TIA			•		•					•								•		•		
TUT	•				•					•											•	
UCT	•			•	•	•		•		•	•			•		•		•	•	•	•	
UFH	•			•															•		•	
UFS	•				•																	
UJ	•			•				•								•						•
UKZN	•			•																	•	
UL	•																					
Unisa	•				•	•				•												
UP	•							•		•									•			•
UWC	•					•				•				•					•			•
Wits	•			•	•	•				•	•	•	•			•		•	•	•	•	

4 ARC: Agricultural Research Council
CSIR: Council for Scientific and Industrial Research
CUT: Central University of Technology
DUT: Durban University of Technology
MUT: Mangosuthu University of Technology
Necsa: South African Nuclear Energy Corporation
NMMU: Nelson Mandela Metropolitan University
NWU: North-West University
RU: Rhodes University
SANEDI: South African National Energy Development Institute

Institution	Fossil									Energy Efficiency and Storage					Other Relevant Fields						All Fields
	Gas	Shale gas	Syngas	Clean coal	Biomass-coal composites	Coal	Pyrolysis/Gasification	Combustion	UG gasification	Energy efficiency	Biohydrogen	Hydrogen	Energy storage	Electrochemical storage	CCS	Environmental impact	Techno-economics/Modelling/Management	Coal Mining/Engineering	Alternative transportation	Socio-economics of biofuels	
ARC									•												••••
CSIR									•				•	•		•	•			•	•••••••••••
CUT																					•••
DUT											•	•									••••••
Eskom	•			•	•	•		•	•	•					•	•					•••••••••••••••
MUT											•										••••••
Necsa																					•
NMMU					•																•••••
NWU				•	•	•	•	•	•	•		•	•			•	•				•••••••••••••••••••••
RU											•										•••••••
SANEDI	•	•											•		•						••••••••••
SASA							•	•													••••
Sasol	•		•			•			•										•		•••••••••
SU							•	•	•								•				••••••••••••••
TIA																			•		•••••
TUT										•	•		•			•					•••••••
UCT							•	•													••••••••••••
UFH																					•••••
UFS																					•
UJ																				•	•••••
UKZN									•		•										••••
UL													•	•							••
Unisa							•	•	•												••••••
UP													•				•	•			•••••••
UWC												•									••••••
Wits			•					•	•		•							•			•••••••••••••••••

4 SASA: South African Sugar Association
SU: Stellenbosch University
TIA: Technology Innovation Agency
TUT: Tshwane University of Technology
UCT: University of Cape Town
UFH: University of Fort Hare
UJ: University of Johannesburg
UKZN: University of KwaZulu-Natal
UL: University of Limpopo
Unisa: University of South Africa
UP: University of Pretoria
UWC: University of the Western Cape
Wits: University of the Witwatersrand

3.2 Towards a Diversified Energy Landscape

Amidst mounting international pressure to mitigate climate change, the South African government announced (in 2009) its intentions to reduce GHG emissions by 34% by 2020 and 42% by 2025 below the "business as usual" scenario. The National Climate Change Response White Paper clarifies the objectives by quantifying the business-as-usual trajectory against which the efficacy of South Africa's collective actions to reduce GHG emissions are measured (DEAT, 2011). Government is planning for a carbon tax of approximately R120 per ton of CO_2 in the 2015 budget. National Treasury released the Carbon Tax Paper for public comment in May 2013 (National Treasury, 2013c). Therefore, while maintaining the country's basic energy supply, the country is in transition from a coal-intensive energy base, to an energy mix where alternatives such as renewable energy (and possibly nuclear power) have a significant share. The National Planning Commission (NPC) recommended a well-designed carbon-budgeting system that would, *inter alia*, benchmark South Africa's total carbon budget against the national GHG trajectory range (NPC, 2012).

The 2010 IRP had the overall objective of reducing the quantity of coal-fired power generation in the country's energy mix in order to meet the reductions in GHGs as stated in the Copenhagen Pledge of 2009. By increasing proportions of gas, nuclear and various renewables, coal-fired energy will be commensurately reduced from 92% in 2010 to 56% in 2035 and is forecast to be 22% by 2065 (DoE, 2010).

Other drivers for a transformed energy landscape include the need to develop the knowledge economy, human capital development and energy security.

3.3 Renewable Energy (Non-bio) in South Africa

3.3.1 Introduction

The introduction of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has created significant growth of the renewable energy industry in the country. Investment in South Africa's renewable energy sector experienced explosive growth in the past few years with investment of more than $5.5 billion in 2012, up from a meagre $30 million in 2011. South Africa's leading position has been secured through a supportive policy environment, coupled with a secure investment framework established by the DoE's REIPPPP. This programme will contribute significantly towards the South African government's aim to ensure diversification of the country's energy mix. The priority areas for South Africa from a renewable energy perspective, given the policy direction, are those of solar, wind and bioenergy resources.

South Africa has about 280 TW of unexploited solar energy, with the highest potential in the western and north-western parts of the country (CRSES, 2013a). Electricity from the sun is harnessed by employing photovoltaic (PV) and concentrating solar power (CSP) technologies.

Although CSP is currently expensive compared with fossil fuel-based plants and will need a variety of incentives to make it cost-effective, South Africa could position itself as a leading global player in CSP in the future. The materials used to construct CSP plants are (mostly) readily available and many of the components can be manufactured locally: 60% of CSP systems could be manufactured locally, with little government support according to the South African Renewables Initiative (SARi) (the dti, 2011).

A local CSP industry can be driven towards greater commercialisation through the development of local value chains which is expected to decrease the price of electricity from CSP systems in order to compete with conventional electricity generation (Edkins *et al*., 2010).

An example of CSP hybridisation is solar steam augmentation which can be used to increase a conventional power station's electricity production, or it can be used to reduce the amount of fossil fuel required. Either way leads to the reduction in the carbon footprint of the cumulative production of electricity. It is estimated that steam augmentation plants are likely to reach economic feasibility earlier than standalone CSP systems (Turchi *et al*., 2011).

The planned South Africa Solar Energy Technology Road Map (SETRM, 2014), currently in draft stage, envisages the creation of a knowledge base for growing the market for PV (utilising crystalline silicon [wafer, cell]) in the country and elsewhere in Africa. The following R&D activities are highlighted, over the next five years:

- *advanced photovoltaic (PV) cell and module characterisation and performance verification;*
- *building integrated photovoltaics (BIPV): the appropriate design of passive solar features, the PV system and integration thereof, and the domestic solar water heater;*
- *development of concentrator photovoltaic (CPV) technology for deployment in South Africa, and elsewhere;*
- *basic investigation of new PV technologies.*

Other solar applications include thermal heating and cooling applications in the agricultural and industrial sectors for space heating in factories, steam generation for production processes, drying applications, and desalination (Holm, 2009). Solar geysers for the domestic market are well established.

The potential of all solar energy technologies in the country vastly exceeds the current and future energy needs. The cost of PV technology, as one of several solar energy options, has decreased significantly over the last five years making it cost competitive with electricity sold by most municipalities in South Africa. The IRP update report released in November 2013 (not approved at time of publication of this report) states that given the recent reduction in the cost of PV generation, the future allocation for utility scale PV power stations may be as high as 9.77 GW by 2030.

A significant onshore wind resource is also available in the country, as indicated in a study conducted by the CRSES at SU (CRSES, 2013b). This report concluded that for the International Electrotechnical Commission wind classes of 3 to 7, a total wind turbine installed capacity of 76.1 GW and corresponding annual generation capacity of 177 TWh is technically feasible. The potential is greatest along the southern and north-east coastline (and associated inland regions). Wind farms offer the largest immediate potential for input into the national electricity grid, and for significantly alleviating South Africa's power supply shortage.

A hitherto unquantified potential resource of electricity generation in South Africa is the ocean. Along the South African coast, waves and ocean currents can be converted into energy. The Agulhas Current flows adjacent to the shelf along the south-eastern seaboard of South Africa and is one of three major western boundary currents in the world's oceans. As such, it has been recognised as a potential source of power which could be generated by deploying underwater turbines in the current and could potentially produce about 40 GW of generating capacity.

Hydropower potential is limited due to the small number of rivers suitable for generating hydroelectricity and current and projected water limitations in the country (ERC, 2007). Small-scale hydro-energy (and biomass energy; see the paragraph on bio-energy) has good potential for distributed small-scale energy generation (in combination with smart grid solutions and small-scale storage solutions).

3.3.2 Research Activities and Funding

Table 3.2 highlights R&D activities in this category as reported by respondents, and **Figure 3.1** highlights collaborations.

Table 3.2: Renewable energy (non-bio) research sub-fields, key collaborators, outputs and funding by institution

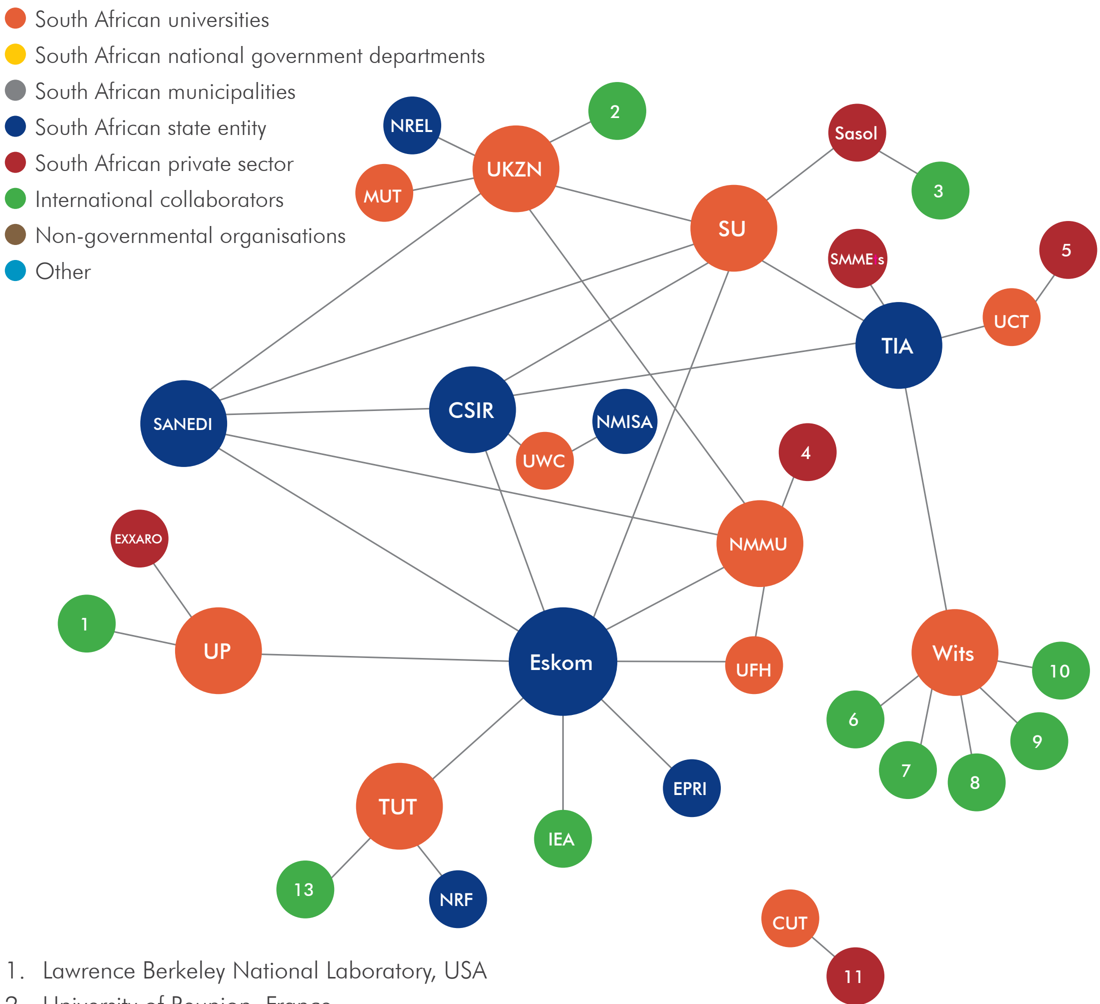
Institution	Field within sector	Key collaborators	Outputs	Funding
CUT	Photovoltaic systems, solar thermal energy, wind energy	Rhino – Green House at Crossways	3 journal papers 6 conference papers	No information
Eskom	Photovoltaic systems, ocean energy, solar thermal energy, wind energy and biomass	SANEDI, CSIR, SU (CRSES), NMMU (Centre for Energy Research – CER), UFH, International Energy Agency (IEA) Ocean Energy Systems, Economic Policy Research Institute (EPRI)	Research reports – mostly confidential	Eskom Holdings SOC Ltd. as per applications considered by National Energy Regulator of South Africa (NERSA)
NMMU	Solar thermal energy, wind energy	Renewable energy (RE) equipment manufacturers	No information	Eskom R700 000 p.a., Automotive Industry Development Centre (AIDC)/Manufacturing, Engineering and Related Services: Sector Education and Training Authority (MERSETA) R400 000 p.a., NMMU R30 000 p.a.
NMMU	Solar thermal energy, wind energy	No information	No information	RECORD in collaboration with *GIZ* – R3.25 million (2013–2015) for the establishment of a PV yield, training and integrity testing facility
SANEDI	Photovoltaic systems, ocean energy, solar thermal energy, wind energy	SU, NMMU, CSIR, UKZN, and most South African universities	University research outputs through funded and demonstrable pilot projects	DoE
Sasol	Solar thermal energy, wind energy, alternative transportation, photovoltaics	International private industries	No information	Sasol

Institution	Field within sector	Key collaborators	Outputs	Funding
TIA	Solar thermal energy, wind energy, alternative transportation	Small, medium and micro enterprises (SMMEs), SU, Wits, NMMU, UCT, CSIR	Renewable energy and technology transfer	No information
TUT	Solar water heaters	NRF, Eskom, and international organisations	8 Masters students 5 PhD students 15 journal papers 30 conference papers	*GIZ* (2013) R700 000
UCT	Photovoltaic systems, solar water heaters, solar thermal energy, wind energy	Project developers	14 journal papers (2013) 13 journal papers (2012)	No information
UFH	Photovoltaic systems, solar water heaters	NMMU	4 Masters students 6 PhD students 15 journal papers 23 conference papers	Technology and Human Resources for Industry Programme (THRIP) (2013) R1.8 million p.a. Eskom R4 million p.a. DST R700 000 p.a.
UKZN	Solar thermal energy, radiometry	SU – Solar Thermal Energy Research Group (STERG), National Renewable Energy Laboratory (NREL), NMMU, University of Reunion, MUT	No information	Group for Solar Energy Thermodynamics (GSET) R200 000 p.a.
UP	Photovoltaic systems	Eskom, Exxaro, Lawrence Berkeley National Laboratory	66 Honours students 31 Masters students 10 PhD students 109 journal papers 176 conference papers 2 books 288 research papers	UP R10m over 2 years, Clean Coal R2.5 million p.a. from the South African Research Chairs Initiative (SarChI), Energy Efficiency and Demand Side Management (EEDSM) R29 million over 5 years from SANEDI, Exxaro R3.5 million over 2 years (2012, 2013)
SU	Ocean energy, solar thermal energy, wind energy	All major South African universities, Eskom, Sasol, CSIR	100 Masters students > 20 PhD students	DST/NRF R8 million p.a., Eskom R3.8 million p.a., Sasol R2 million p.a., SA Industry R1 million p.a., provincial government R1.5 million p.a., project R3 million p.a.

Table 3.2: Renewable energy (non-bio) research sub-fields, key collaborators, outputs and funding by institution (continued)

Institution	Field within sector	Key collaborators	Outputs	Funding
UWC	Photovoltaic systems	CSIR, National Metrology Institute of SA (NMISA)	10 Masters students 5 PhD students >20 journal articles >20 conference papers	DST (2007–2014) R180 million, Eskom (2000–2014) R50 million, THRIP (2000–2014) R18 million, PetroSA (2010–2014) R36 million, Water Research Commission (WRC) (2014) R1.5 million, Eskom (2013) R600 000, Sasol (2014) R300 000 NRF (2014) R800 000, Eskom R750 000, NRF R200 000; NNR R215 000
UWC	Photovoltaic systems, hydrogen economy	CSIR, NMISA	8 Masters students 3 PhD students 15 journal papers 10 conference papers	UWC (2012) R20 000, NRF (2012) R400 000, UWC (2013) R120 000, NRF (2013) R200 000
Wits	Photovoltaic systems, solar water heaters, solar thermal energy, wind energy	DST/NRF Centre of Excellence in Strong Materials-Wits, CNR-IFN (Italy), Enrico Fermi Institute(Italy), Chalmers University (Sweden), Dresden University (Germany), Polytechnic of Namibia	3 Masters students 3 PhD students 38 journal papers 18 conference papers	Wits R10 million for 5 years

Renewable Energy



1. Lawrence Berkeley National Laboratory, USA
2. University of Reunion, France
3. International private industries
4. Renewable energy equipment manufacturers
5. South African private sector
6. CNR-IFN, Italy
7. Enrico Fermi Institute (Italy)
8. Chalmers University (Sweden)
9. Dresden University (Germany)
10. Polytochnic of Namibia
11. Rhino Group (House Rhino, Crossroads Farm Village)
12. International organisations

Figure 3.1: Diagrammatic representation of collaborations between institutes and organisations involved in renewable energy research

3.3.3 Findings and Key Messages

Findings

The survey responses of researchers active in the field of renewable energy research highlighted a lack of human capital and research funding as two of the key factors limiting work in this field. Although information on funding of renewable energy (non-bio) is far from complete (**Table 3.2** and **Figure 3.1**), a rough estimate of the annual investment in research, based on information provided, is approximately R600 million. Of this amount, only just over R12 million per annum is contributed by the private sector (excluding THRIP) (mainly Exxaro, Sasol, PetroSA). The lack of funding may be exacerbated by the fact that, to date, the penetration of renewable energy in South Africa has been limited and also mainly restricted to niche markets such as off-grid, rural applications. It is anticipated, however, that this will change with the implementation of government's REIPPPP.

There is a striking lack of collaboration among researchers at universities in South Africa and with the exception of a small number of universities, international research collaborations are minimal (**Table 3.2**). There also seems to be insufficient coordination between the major role players, DST, DoE, Eskom, SANEDI and others, which has contributed to the fragmentation of effort and funding in this sphere.

A number of respondents highlighted the need for suitable renewable energy research and test laboratories, including national facilities in areas with significant wind and solar resources.

Key Messages

A general, consistent message was that national government should consider putting a significant, long-term funding model and an appropriate structure in place to support research in this field. This programme should recognise that the current expertise in this field of research is spread out over the country at a variety of universities and research institutions. Such a programme should be centrally funded and coordinated but may include many role players, including the DST, DoE, SANEDI, Eskom, and private companies interested in energy research, such as the renewable energy independent power producers (IPPs). Funding should be made available to support larger research projects and especially make provision for bursaries for postgraduate students and postdoctoral fellows. The proposed structure could then also act as a repository of information and data relevant to research in renewable energy. Such a structure could also be extended to include other partners in southern Africa.

A sustained policy of procuring renewable energy as part of the IRP should be supported in order to ensure that the current research activities in the field are supported and funded. Only if there is a sustained market for renewable energy in South Africa, especially at the utility scale, will there be take-off of the technology and graduates that will emanate from this research programme.

Small-scale, off-grid renewable energy systems, especially for poor people in rural areas, should also be included as a priority area for research as this is one sector where South Africa needs to make significant progress in the next few years. It is also part of the mandate of government to create jobs and improve the standard of living of poor South Africans and these priorities need to be addressed in any government-funded research programme.

3.4 Bio-energy in South Africa

3.4.1 Introduction

Bio-energy refers to renewable energy obtained from biological sources where energy is acquired through a process of biological carbon fixation. An uncertain long-term fossil fuel supply, increasing CO_2 emissions, as well as unstable fuel prices have encouraged research into bio-energy production, which envisages replacing and/or supplementing our current dependency on fossil fuel. Biomass can be converted by either thermal, chemical, or biochemical conversion, resulting in solid, liquid or gas fuels (Demirbas, 2008).

Biofuels (liquid or gaseous, produced from organic material or biomass) are a potential replacement for fossil fuel-based fuels. Biofuels, including bioethanol, biomethanol, biodiesel and biohydrogen, are categorised into conventional (first generation) biofuels (based on feedstocks, such as corn, cereals, canola and soybean) and advanced (second generation) biofuels (based on cellulosic feedstock, such as straw, bagasse, rice husks, organic waste and algae) (WBA, n.d.). Second generation biofuels are mainly in the pre-commercialisation or early commercialisation phases.

In 2007, South Africa released the Biofuel Industrial Strategy (DME, 2007a), which included a five-year pilot programme. As set by the White Paper on Renewable Energy, the Department of Minerals and Energy (DME) envisioned that by 2013, biomass energy would contribute 35% of the national target for renewable energy production, with the remainder being supplied by solar and wind. Furthermore, a 2% biofuel penetration into the national liquid fuels pool by 2013 was envisaged, which translates into 400 million litres of biofuel per annum (DME, 2007a). This goal has not been reached. A mandatory blending of petrol and diesel with biofuels has been set for October 2015 (RSA, 2014), with the policymaking provision for 50% and 100% fuel tax exemptions for biodiesel and ethanol respectively. A focus on new and additional agricultural land is intended to alleviate food security concerns.

The successful development and deployment of second generation technologies could play a significant role in South Africa's transport fuel future by potentially replacing 70% of current fossil fuel usage from around 50% of available lignocellulosic biomass (Lynd *et al.*, 2003).

Multiple research projects are underway at a number of institutions, as highlighted in **Table 3.3**.

Among the main challenges of biofuels are the relative low energy density of biomass and the associated cost of concentrating (gathering/transporting) biomass to achieve economy of scale. Hence biomass plants make more sense in regions where biomass concentrations are highest. Another major issue to be dealt with is food security. Hence, second generation biofuels are needed.

3.4.2 Research Activities and Funding

Table 3.3 highlights R&D activities in this category as reported by respondents, and **Figure 3.2** highlights collaborations.

Table 3.3: Bio-energy research sub-fields, outputs and funding by institution

Institution	Field within sector	Key collaborators	Outputs	Funding
ARC	Waste to energy, food crops to energy, biogas, biodiesel	ARC – Biotechnology Platform, ARC – Grain Crops Research Institute, Pioneer Plastics	1 MSc student 2 conference papers Several pamphlets on renewable energy	ARC Parliamentary grant R800 000
CSIR	Biodiesel, microalgae to energy, bioethanol, biogas, waste to energy, environmental impact of biofuel production, socio-economic impact of biofuel production, life-cycle assessment of biofuel production, sustainability of biofuel production	No information	Too many to detail	DST, Department of Environment Affairs (DEA), TIA, CSIR, SANEDI, Eskom, private clients
DUT	Biodiesel, biohydrogen, biogas, microalgae to energy, waste to energy	National and local government, water utilities and other tertiary institutions	13 journal papers 4 book chapters 17 conference papers	NRF, eThekwini Municipality, TIA, CSIR R300 000–R500 000 p.a.
Eskom	Waste to energy, biomass co-firing, microalgal biomass	SANEDI, Wits, IEA Bio Energy, CSIR, VGB, NWU, Eskom Power Plant Engineering Institute (EPPEI), NMMU, UFH	Technology scanning reports Techno-economic evaluation reports Testing and investigation reports Concept and basic design reports	Eskom
MUT	Microalgae to energy, Waste to energy, bioethanol, biohydrogen, biogas, biodiesel, bioether	Private industry, government	1 PhD student 5 journal papers	No information
NMMU	Bio-oil, microalgae to energy, biomass-coal composites	UCT (Department of Chemical Engineering), Eskom/ Exxaro; Hatch-Goba	4 MSc students 5 PhD students 1 trademark registration 5 patent applications, Several conference papers	DST R19.3 million (Sept 2011–Sept 2014)
NWU	Bio-paraffin, biodiesel, bio-oil, bioethanol, biobutanol, biogas, microalgae to energy, macroalgae to energy, non-food crops to energy, waste to energy, co-combustion/pyrolysis/ gasification	Academic organisations, ARC, Department of Agriculture, Forestry and Fisheries (DAFF), European Union (EU)	2 PhD students, 14 MSc students, 57 Honours students, 8 journal papers, 3 postdoctoral fellows, 32 conference contributions	2007: R1.5 million (SANERI), 2008: R1.6 million (SANERI), 2009: R1.86 million (DST), 2010: R1.23 million (DST), 2011: R2 million (DST), 2012: R1.23 million (DST); R2.6 million (NRF), 2013: R1.9 million (NRF), 2014: R1.9 million (NRF) **All the above amounts exclude student bursaries*

Institution	Field within sector	Key collaborators	Outputs	Funding
NWU	Waste to energy, co-combustion/pyrolysis/ gasification	Sasol	4 MSc students 5 PhD students >10 journal papers 19 conference papers	2012: R600 000 (Sasol), 2013: R400 000 (Sasol) **Approximately half of the above funding was spent on bio-energy research (coal-biomass interactions)*
RU	Biodiesel, biogas, microalgae to energy	No information	6 MSc students 6 PhD students 18 journal and conference papers 2 provisional patent applications	Sasol, The Mvula Trust, East London Industrial Development Zone (ENBW), THRIP
RU	Microbial fuel cells, waste to energy, microalgae to energy, non-food crops to energy, biohydrogen, biogas	Biogas SA, academic institutions	1 MSc student 3 journal papers	Eskom, World Wildlife Fund (WWF) R200 000
SANEDI	Microalgae to energy, macroalgae to energy, waste to energy	Algal Bio-Energy Platform (ABP), eThekwini Municipality, Biojet working group	University research outputs through funded and demonstrable pilot projects Chair in biofuels (2010) Associate Chair in biofuels (2010)	N/A (either leverage funding or enter into joint funding agreements with another funder/industry)
South African Sugar Association (SASA)	Non-food crops to energy, bioethanol, co-combustion/pyrolysis/ gasification	Academic institutions, particularly SU and UKZN	8 MSc students 5 PhD students 10 journal papers several conference papers	Industry, THRIP
Sasol	Waste to energy, non-food crops to energy, syngas	Local and international universities	Articles and conference contributions. Main objectives are to create growth opportunities for the company, as well as support to existing business.	Sasol internal funding
TIA	Microalgae to energy, biodiesel	No information	No information	No information
TUT	Biodiesel, microalgae to energy	No information	In progress: 6 B Tech students 1 PhD student 2–3 journal papers	No external funding
UCT	Microalgae to energy, macroalgae to energy, waste to energy, non-food crops to energy, bioethanol, biohydrogen, biogas, biodiesel, bio-oil, feasibility of biofuel production	SANEDI, start-up companies, Anglo Coal, SA Breweries, WRC, Cambridge University	7 MSc students 2 PhD students 9 journal papers 3 book chapters 10 conference papers	SANEDI and NRF through SARChI Chair, WRC, SA Breweries

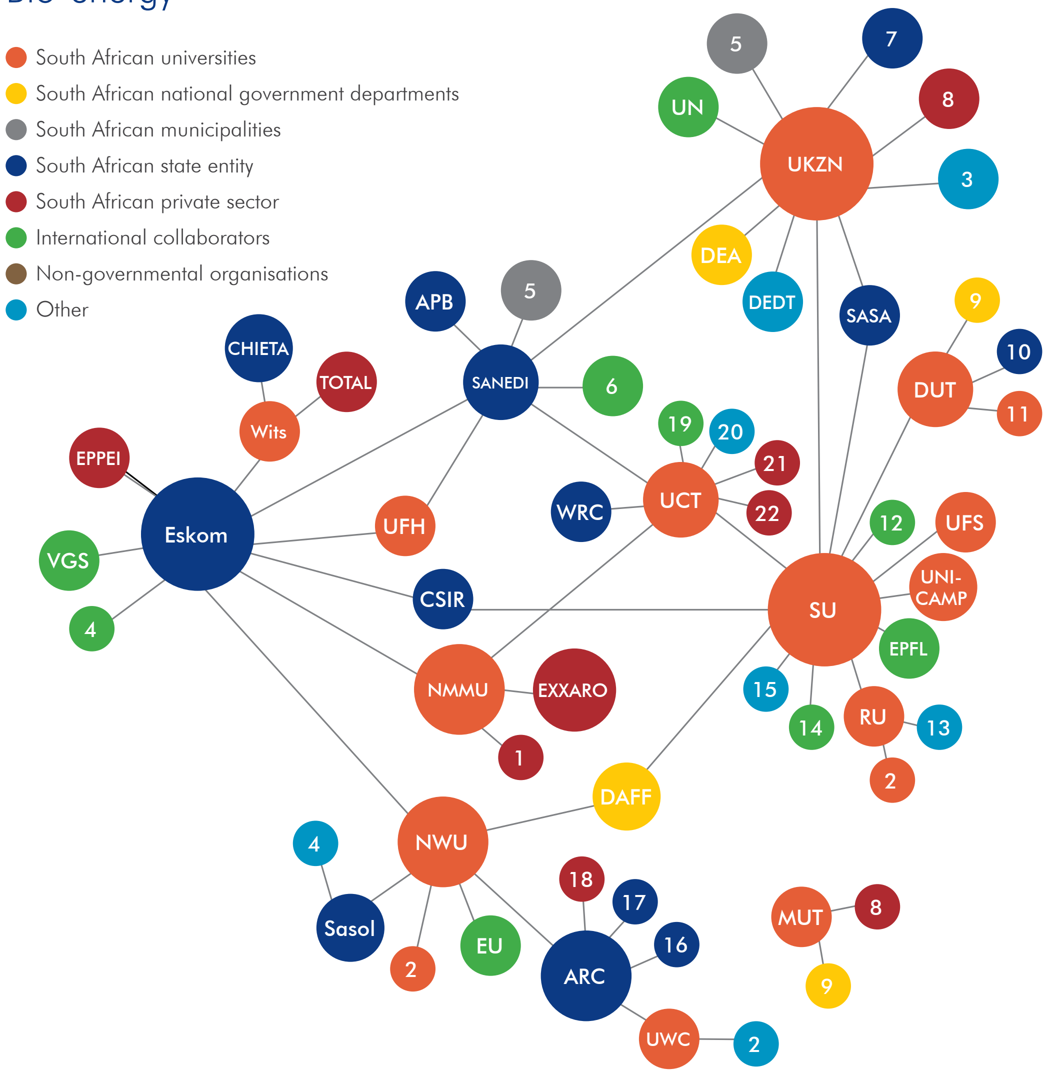
Table 3.3: Bio-energy research sub-fields, outputs and funding by institution (continued)

Institution	Field within sector	Key collaborators	Outputs	Funding
UFH	Biogas, co-combustion/ pyrolysis/gasification	SANEDI, Eskom	3 MSc students 3 PhD students 16 journal papers 3 book chapters 21 conference papers	2009: R300 000 (Eskom) 2010: R300 000 (Eskom), 2011: R380 000 (Eskom/NRF), 2012: R450 000 (Eskom/NRF), 2013: R500 000 (Eskom/NRF), 2014: R3 million (SANEDI), R650 000 (Eskom/NRF/TIA)
UFS	Bioethanol	Department of Chemical Engineering, SU	1 MSc student 1 journal paper 6 conference papers	R240 000 (NRF), R60 000 (UFS)
UJ	Biogas, waste to energy, socio-economic impact of biofuel production	No information	5 conference papers	R1.3 million SANEDI R400 000 (University of Johannesburg, University Research Committee (UJ, URC) and Faculty of Engineering and the Built Environment (FEBE) Faculty Research Committee (FRC))
UKZN	Biogas, biohydrogen	No information	5 journal papers	R250 000
UKZN	Waste to energy, biohydrogen, biogas	eThekwini Municipality, KwaZulu-Natal Department of Economic Development and Tourism (KZN DEDT), DEA, SANEDI, lottery, private industry, National/ International academic institutions, United Nations (UN)	Several MSc students 4 PhD students 10 journal papers >10 conference papers	2013: R1 million (KZN DEDT), R500 000 (local municipality), 2014: R450 000 (local municipality), R6.4 million (Industry), R2.6 million (THRIP), R5.05 million (Industry), R3.95 million (THRIP) LOTTO, NRF
Unisa	Biodiesel, bioethanol	No information	8 journal papers 3 book chapters 7 conference papers	No information
Unisa	Waste to energy, Biodiesel, microalgae to energy, co-combustion/ pyrolysis/gasification	No information	1 MSc student 2 PhD students 7 journal papers 2 conference papers	R10 million (private investor), R300 000 (NRF)
UP	Biodiesel, hydrological studies on biofuel production	No information	> 30 journal papers 2 book chapters	WRC, NRF
SU	Bioethanol	Dartmouth College, USA, *Universidade Estadual de Campinas* (UNICAMP), Brazil, RU	14 MSc students 5 PhD students 61 journal papers 14 patents 59 conference papers	NRF (2014): approx. R1.6 million

Institution	Field within sector	Key collaborators	Outputs	Funding
SU	Bioethanol, co-combustion/pyrolysis/gasification, life-cycle assessment	No information	13 MSc students 7 PhD students 42 journal papers	Shared SARChi Chair, TIA, THRIP, Industry R4 million–R7 million
SU	Macroalgae and microalgae cultivation and conversion of algae biomass to biogas and liquid fuels	*École polytechnique fédérale de Lausanne* (EPFL), Switzerland, Arizona Centre for Algae Technology and Innovation (AzCATI), Arizona State University; UKZN, DUT; UCT, CSIR, DAFF	Since 2012 (bioenergy sector): 8 MSc students 2 PhD students 1 journal paper 25 conference papers	2012–2014: R400 000 (Society, Ecosystems and Change (SEAChange) programme – NRF), 2012: R300 000 (SA-Swiss bilateral seed funding (NRF))
SU	Waste to energy, food crops to energy, non-food crops to energy, bioethanol, biogas, biodiesel, co-combustion/pyrolysis/gasification	Wide network across industry, government and the wider NSI	3 MSc students 1 PhD student 15 journal papers 4 book chapters 16 conference papers	DST, NRF, Eskom, Contract R&D
UWC	Non-food crops to energy, bioethanol, biodiesel	ARC, various academic institutions	No information	DST (2007–2014) R180 million, Eskom (2000–2014) R50 million, THRIP (2000–2014) R18 million PetroSA (2010–2014) R36 million, WRC (2014) R1.5 million Eskom (2013) R600 000, Sasol (2014) R 300 000, NRF (2014) R 800 000, Eskom R750 000, NRF R200 000, NNR R215 000*
Wits	Biodiesel, microalgae to energy, waste to energy, food crops to energy, biogas, biohydrogen, microbial fuel cells	No information	2 MSc students 3 PhD students 5 journal papers 3 patents	No major funders at present
Wits	Waste to energy, bioethanol, biogas, biodiesel, syngas, bio-oil	Total Oil, Chemical Industries Education and Training Authority (CHIETA)	3 PhD students 4 patents	CHIETA

**These amounts are duplicated from Table 3.3 and may not be specifically for bio-energy research*

Bio-energy



1. Hatch-Gaba
2. Academic organisations
3. Local and international academic organasations
4. IEA Bio-energy
5. eThekweni Municipality
6. Biojet working group
7. Lottery
8. Private industry
9. National an local government
10. Water utilities
11. Tertiary institutions
12. Dartmouth College, USA
13. Biogas South Africa
14. Arizone State University, USA
15. Various National System of Innovation organisations
16. ARC – Biotechnology Platform
17. ARC – Grain Crops Institute
18. Pioneer Plastics
19. Cambridge University, UK
20. Start-up companies
21. Anglo Coal
22. South African Breweries

Figure 3.2: Diagrammatic representation of collaborations between institutes and organisations involved in bio-energy research

3.4.3 Findings and Key Messages

Findings

The most striking finding is the large number of institutions (>20) engaged in bio-energy research in South Africa (**Figure 3.2**). Research is focused mainly on the production of biogas and biodiesel. Research into bio-energy sources includes a focus on waste materials, second generation crops and macro and micro-algae. Energy production from plant materials mainly focuses on non-edible plant material, as well as crops, as these can produce both energy and food in a single crop. Relatively little research interest is shown in production of bioethanol and biohydrogen, as well as the use of biomass in thermochemical applications such as carbonisation, torrefaction, liquefaction, combustion, pyrolysis and gasification. New horizon research fields include the production of bio-chemicals, such as biobutanol, bio-oil, bioether and bio-plastics, as well as the use of microbial fuel cell technology for biofuel and bio-energy production.

The greatest barriers to research in this sector, as reported by survey respondents, are the lack of human resources and funding. A lack of engineering students available for postgraduate study was mentioned by a few institutions. This is a general concern for all research fields requiring specific engineering skills.

Funding concerns related to student bursaries; R&D running costs; equipment costs, especially large and expensive analytical and specialised equipment; infrastructure costs, including staff offices, laboratories, student offices; human resources, including administrators and technical staff; and laboratory equipment maintenance and repair. It was noted that often grants would exclude these expenses, making it difficult for research groups to be sustainable.

Funders in the bio-energy sector include: NRF, DST, TIA, THRIP, SANEDI, Eskom, Sasol, WRC, WWF, DEA, CSIR, ARC, municipalities, private companies, LOTTO, SA Breweries, etc. Respondents have not provided comprehensive information on funding amounts, however, a rough minimum estimate from information provided gives a total investment of about R30 million per annum. A few institutions that are engaged in research indicate that they have no external research funding. Some (e.g. UKZN, UWC and SU) have been successful in leveraging significant funding from industry. Funding for pilot-scale activities is mostly limited to TIA and the dti and funding can only be procured for commercialisation and not for pilot-plant demonstration.

Despite good policy instruments (See Section 3.3.1), a lack of government commitment to a long-term strategy regarding biofuels and bio-chemicals incorporation into the economy is hampering research in biomass conversion technologies in general. Legislation and a lack of standards for many bio-based products make the commercialisation of technologies for these products very difficult.

According to the responses received, outputs from the bio-energy sector over the past five years include: 249 journal papers, 19 book chapters, 205 conference contributions, 51 PhD and 86 MSc graduates, one trademark registration and 21 patents.

Key Messages

The following key messages emerged from the survey responses:

- Since bio-energy research is strategic and long term, partnerships and collaborations are required to accomplish strategic objectives. A concerted centralised national effort is required to co-ordinate biomass-related bio-energy R&D and technology diffusion. This is required not only in S&T but also in creating an enabling legislative environment. When these come together, enormous progress can be made. There seem to be many initiatives, but no clear cohesion of research effort that could benefit the South African economy. The creation of the bio-economy hub to coordinate research efforts across the value chain will greatly benefit the industry, as well as create a central source of funding for biofuels and bio-chemicals research.

- Human capital development (HCD) and funding: An effort should be made to make it attractive for engineering students to continue with graduate or postgraduate study. Funding is needed to support, not only postgraduate students, but other staffing, infrastructure and equipment costs, to enhance the capacity of institutions to take on more research.
- Funders should shift their focus from supporting only laboratory-scale studies to funding pilot-scale demonstration initiatives that could lead to commercialisation of products and processes. The development of large-scale systems for industry should be supported.
- Quantification of different feedstocks, with associated techno-economic and sustainability studies, is required.
- Exploration of the opportunities provided by synergies between biomass and fossil fuels as shown by the results of microalgae biomass-coal composites is required. This line of R&D is unique in the world and offers substantial advantages for the efficient utilisation of biomass and for extracting high-value and efficiency from fossil fuels.
- Greater focus on the intensification of renewable energy systems (smaller yet more efficient) is needed. This would require a substantial focus on new technology development as such technologies do not necessarily exist elsewhere. The focus should be not only on importing technology from elsewhere, but also on studying the application of such technology.
- Although biodiesel production from algae has great potential, the commercial production thereof is still restricted due to cost of production at a commercial level. Large-scale production is mainly for various high-value products which is financially more feasible. There are still problems related to isolation, growth, etc. of algal species in order to result in optimal lipid production. There should be an integrated approach to algal products. Life-cycle analysis of large-scale algal cultivation with regard to energy and economics should be undertaken. A method of producing multiple products from a single algal process, that delivers biodiesel and high-value products is expected to ultimately increase the financial feasibility of the process.
- Other research areas requiring support are:
  - The development of computer models for predicting the performance of biogas digesters.
  - The efficient and cost-effective conversion of municipal solid waste into energy in plasma gasifiers.
  - Electricity generation coupled to waste water treatment using membrane-less microbial fuel cells.
  - The application of genomics and bio-informatics for the molecular genetic characterisation of organisms used as bio-agents for the production of biofuels.
  - Co-gasification and co-firing with coal for low carbon power production.

3.5 Nuclear Energy in South Africa

3.5.1 Introduction

Nuclear energy refers to energy generated through fusion, fission or radioactive decay. South Africa's Nuclear Energy Policy outlines a vision of "…becoming globally competitive in the use of innovative technology for the design, manufacture and deployment of state-of-the-art nuclear energy systems, power reactors and the nuclear fuel cycle…". In keeping with this, the DoE announced in its 2010 IRP that nuclear power would contribute 9.6 GW of the planned 42 GW of new electricity generation capacity to be constructed by 2030. The updated IRP 2010–2013 (not approved at time of printing this report) indicates different scenarios for nuclear energy, based on a number of assumptions. The plan states *inter alia* that the decision to procure the additional capacity from nuclear plants can be delayed.

South Africa possesses the sixth largest natural uranium resource in the world, the basic ingredient for nuclear fuel. Therefore, it also intends to implement, or obtain interest in, the complete nuclear fuel cycle including uranium mining and milling, conversion, enrichment and fuel fabrication. Besides providing enhanced security of supply, it would also mean that the country can beneficiate its own natural resources rather than relying on others to do so at significant additional cost. Amongst the different fuel cycle activities, uranium enrichment and fuel fabrication are technologically the most challenging, but also represent the highest value items in the complete value chain.

The nuclear industry in South Africa started in 1959 with a decision by Cabinet to establish a domestic nuclear industry. A number of milestones characterise the development of nuclear energy in South Africa, supported by an intensive R&D programme.

The milestones include: the establishment of the Pelindaba site near Pretoria in 1961; the first criticality of the 20 MWt SAFARI-1 reactor in 1965; the establishment of the Uranium Enrichment Corporation in 1970; and the commencement of an extensive nuclear fuel cycle programme and a nuclear weapons capability. The South African Nuclear Energy Corporation (Necsa) was established in 1999.

From 1971–1975 the Y pilot uranium enrichment plant was constructed, based on the unique Helikon aerodynamic vortex tube process developed in South Africa. The USA stopped exporting highly enriched uranium fuel for the SAFARI-1 reactor as part of economic sanctions against SA. In 1979, the Y-Plant started producing 45%-enriched uranium and the first fuel assemblies for SAFARI-1 from Valindaba were fabricated in 1981. The Y-Plant operations ceased and the plant was dismantled in 1990 under the International Atomic Energy Agency supervision.

From 1984–1997, intensive nuclear fuel production and uranium enrichment programmes were supported. In 1984, the Z-Plant was commissioned and went into full production in 1988, with a capacity of 300 000 SWU/yr. Fuel elements with a 3.25% enrichment were supplied to the Koeberg Nuclear Power Station.

In 1983, a Molecular Laser Isotope Separation (MLIS) programme commenced, with French participation in 1995. In 1997, the MLIS programme was cancelled due to funding constraints and technical challenges. A centrifuge-based R&D programme was supported during the time.

In 1984–1985, two 900 MWe French-built nuclear power plants were commissioned at Koeberg.

In 2007, the draft nuclear energy policy was released (DME, 2007b). This included an ambitious programme to develop all aspects of the nuclear fuel cycle, including: conversion, enrichment, fuel fabrication and also reprocessing of used fuel.

From 1999–2009, South African government, Eskom, Westinghouse and the Industrial Development Corporation (IDC) invested R9.244 billion in the PBMR Project which was closed in 2010. A number of factors led to the closure of the programme in which South Africa was considered to be a world leader. These included the economic climate, public opinion, the PBMR positioning in the DPE while it was in fact still in a R&D phase, unrealistic cost estimates, a change in technical focus, licensing issues, lack of international support, the lack of an interested customer and political factors such as the changing nature of project, unrealistic expectations and a lack of inter-departmental coordination and planning.

The R&D division of Necsa was established on 1 April 2007 to consolidate the research and technology development activities of Necsa and to strengthen the corporation's ability to deliver on the following mandate of Necsa as derived from the Nuclear Energy Act (*Act 46 of 1999*):

- to undertake and promote research on nuclear energy, radiation sciences and technology;
- to process source, special, and restricted nuclear material, including uranium enrichment; and
- to collaborate with other entities in these and related fields.

The Act also provides for the delegation of specific responsibilities to the corporation, including the operation of the SAFARI-1 reactor; applying radiation technology for medical and scientific purposes; decontamination and decommissioning of nuclear facilities from historic strategic programmes; and implementing and executing national safeguards and other international obligations.

The adoption of the Nuclear Energy Policy in June 2008 (DME, 2008) reconfirmed Necsa's mandate, and designated the organisation as the anchor for nuclear energy research, development and innovation in South Africa. The policy also highlighted the need for the corporation to develop viable nuclear fuel cycle options to support South Africa's envisaged nuclear energy expansion programme.

The strategic environment in which the R&D division operates is also informed by:

- the Necsa Long-term Strategy – as approved by the Necsa Board in July 2011;
- the draft Nuclear Energy Research and Development Strategy (NERDIS) – still awaiting approval by DST;
- the IRP 2010 approved by DoE during 2010 and updated in 2013;
- the Necsa contribution to the National System of Innovation (NSI).

With regard to the nuclear fuel cycle, Necsa has adopted a two-pronged approach: the long-term development of the front-end of the nuclear cycle in support of the anticipated "new build" programme and the short-term focus in support of isotope production. With the scaling down to low enriched uranium fuel and target plates, Necsa no longer has complete control over the required fuel and plates. It will be strategically important to re-establish local manufacture of fuel and target plates. Continued laboratory-scale research is essential for retaining personnel and skills required for the pending activities.

Therefore, even though Necsa does not currently perform any nuclear energy research, it is believed that the skills and resources are in place to support a "new build" if the decision is made to implement the NERDIS, which is currently under review.

In terms of funding, Necsa has received approximately R90 million per annum from the DoE and about R50 million per annum from other sources. All of these funds are being spent on the Necsa R&D department and their current initiatives.

During the development of the PBMR, the PBMR company invested in R&D at a number of universities, as well as at Necsa. Work related to the PBMR programme has largely been abandoned.

3.5.2 Research Activities and Funding

Table 3.4 highlights R&D activities in this category as reported by respondents, and **Figure 3.3** highlights collaborations.

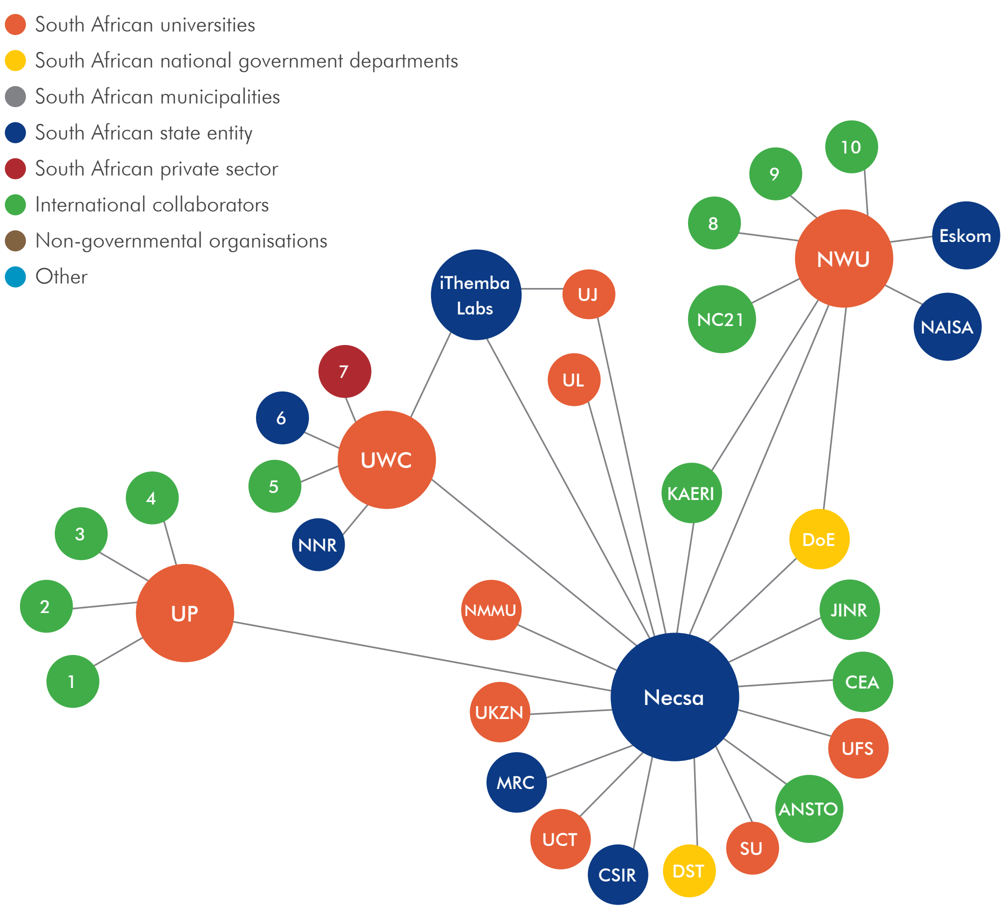
Table 3.4: Nuclear energy research sub-fields, outputs and funding by institution

Institution	Field within sector	Key collaborators	Outputs	Funding
Necsa	Radiation sciences and technology, commercial isotope production	DoE, DST, international partners – Australian Nuclear Science and Technology Organisation (ANSTO), *Commissariat à l'Energie Atomique et aux Energies Alternatives* (CEA), France, Korean Atomic Energy Research Institute (KAERI), Joint Institute for Nuclear Research (JINR) Local partners – UP, NWU, UWC, UJ, SU, UFS, UCT, UL, NMMU, UKZN, iThemba LABS, CSIR, Medical Research Council (MRC)	None	~R90 million p.a. from DoE, ~R50 million p.a. from other sources
NWU	Nuclear reactor and power plant modelling and analysis, nuclear cogeneration and process heat analysis and design, nuclear energy policy studies.	Necsa, Eskom, DoE, Nuclear Industry Association of South Africa (NIASA), National Treasury, KAERI, European Nuclear Cogeneration Industrial Initiative (NC2I)	Several publications in leading international nuclear engineering journals Several papers at international conferences on nuclear engineering and heat and mass transfer Cohort of 10–15 full-time and 2–5 part-time postgraduate students per year.	R2.5 million p.a. for SARChI in nuclear engineering from DST via NRF. R120 000 p.a. from DST in South Africa – South Korea collaboration programme, R700 000 from THRIP via MTech Industrial thermal-fluid project

Table 3.4: Nuclear energy research sub-fields, outputs and funding by institution (continued)

Institution	Field within sector	Key collaborators	Outputs	Funding
NWU	Safety analysis, nuclear policy system design	KAERI, Necsa – Radiation and Reactor Theory (RRT) Group, European Atomic Energy Community, EU Institute for Transuranium Elements (of the Joint Research Centre, Italy), *Institute Jean Rond d'Alembert* (*Universitè et Marie Curie*, France)	No information	DST Chair in Nuclear Energy ~R700 000 p.a. THRIP ~R700 000 p.a.
UJ	Simulation of reactors, radiation physics, environmental impacts, use of nuclear technology	Necsa and iThemba LABS	4 MSc students	NRF ~ R700 000 p.a.
UP	Nuclear materials research	Saha Institute for Nuclear Physics, Kolkata, India, Friedrich-Schiller University of Jena, Germany, *Pontifícia Universidade Católica do Rio de Janeiro*, Brazil, *Universidade Federal do Rio Grande do Sul*, Brazil	Several postgraduate students Several journal papers Several conference papers	UP R600 000
UWC	Nuclear safety	iThemba LABS, Earth Institute in Groningen, NNR, Koeberg Power Station, Goldfields SA	6 MSc students 3 PhD students 1 postdoctoral student 10 journal papers 6 conference papers	Eskom R400 000, NRF R200 000, NNR R215 000 Eskom [Koeberg] R350 000

Nuclear Energy



1. Saha Institute for Nuclear Physics, India
2. Fredrich-Schiller University Jena, Germany
3. Pontifícia Universidade Católica do Rio de Janeiro, Brazil
4. Universidade Federal do Rio Grande do Sul, Brazil
5. Earth Institute in Groningen, Netherlands
6. Koeberg Power Station
7. Goldfields South Africa
8. European Atomic Energy Community
9. EU Institute for Transuranium Elements, Italy
10. Intstitute Jean Rond d'Alembert, France

Figure 3.3: Diagrammatic representation of collaborations between institutes and organisations involved in nuclear energy research

3.5.3 Findings and Key Messages

Findings

Most survey participants reported human resources, infrastructure and funding as the main limiting factors in terms of their current research capability. The lack of human resources is borne out by the low number of students being trained in this field (**Table 3.4**). The funding limitation impacts on both possible human resources (both students and professional level supervisors) which cannot be retained, nor offered an attractive career path, as well as infrastructure. Research (but specifically mentoring and supervision) in the field of nuclear energy is very intensive due to the limited undergraduate exposure of students to the field.

According to the data reported in **Table 3.4**, with the exception of Necsa funding, the total annual investment into nuclear energy research is only R3.86 million. Although Goldfields is reported as a collaborator with UWC, there is no indication of private sector funding.

Nuclear energy research is concentrated at a few universities (NWU, UJ, UP and UWC), although Necsa indicates a partnership with some additional universities that have not provided survey responses (SU, UCT, UL, NMMU and UKZN). It is striking that all the universities listed in **Table 3.4** are working in isolation, indicating collaborations only with Necsa and iThemba LABS (**Figure 3.3**). This observation strongly supports the need identified by survey respondents for focused research effort in the form of a CoE in nuclear energy, which could repackage and reshape all related work in the country, and argue coherently for its vision and funding.

Necsa is currently focusing research and development efforts in the field of nuclear medicine and not nuclear energy. It was, however, emphasised that Necsa (as a result of the deliberate "two-pronged approach" to their research programme) claims to have all the relevant skills and resources available to facilitate the design and implementation of nuclear energy reactors if/when government decides to move ahead with plans to increase the energy capacity in the country through nuclear energy.

Research in nuclear energy performed at the four academic institutions mentioned above includes: thermal fluid systems modelling, thermal fluid systems design, test facility implementation, reactor analysis and design, process heat applications, high temperature reactor materials, permanent magnet synchronous machines, multiphysics, multiscale modelling and control, process modelling, fault tracing, diagnostic and neural networks and nuclear regulation and policy.

Key Messages

Participants stated that the biggest challenge in terms of nuclear energy research is the negative public perception of nuclear energy. To this end, studies focusing on nuclear safety (both in terms of the operation of reactors and the safe discarding of nuclear waste products) and on nuclear policy should be performed.

Participants recommended investment of time and money in the following areas:

- "New build" of nuclear power reactors to cope with energy demand in South Africa, reactor safety and responsible disposal of nuclear waste.
- All R&D aspects related to the envisaged localisation programme which is planned to form part of the procurement plan.
- Thermal hydraulics expertise is lacking in South Africa.
- Research is limited by a lack of experiential infrastructure and access to data of current nuclear reactors.

- Both open source and commercial modern simulation capacity – the open source aspects can be international and web-based to lower the threshold generally for entry into simulation, thus building public confidence and transparency in the study of existing and future reactors. This can also lay the foundation of increasing South African capacity in design and manufacture.
- The development of capacity in the characterisation of nuclear materials, and the production of new nuclear materials. This can be applied to many aspects, including safety, security, environment, manufacturing.
- Radiation safety local expertise for any new power reactors; radiation safety local expertise for new uranium mining.

3.6 Fossil Fuel Energy in South Africa

3.6.1 Introduction

The impact of fossil fuel use on global climate change is well documented (e.g. IEA, 2013). South Africa is a significant GHG emitter, producing approximately 500 million tons of carbon dioxide equivalent (CO_2e) per year from coal-fired operations. In global rankings, South Africa ranks 12th in the world, producing 1% of global CO_2. Around 77% of South Africa's energy needs are directly derived from coal (DoE, 2014), with coal supplying approximately 92% of the primary energy and about 40% of the country's liquid fuel. In addition, coal supplies heat and power to an estimated 6 000 smaller-scale industrial users for process heat and power, including the pulp and paper, sugar, brick and tile, cement and lime, food and chemical industries.

The updated IRP 2010 promotes more flexibility in planning as events and policies unfold (DoE, 2010). All scenarios presented in the IRP 2010, except Big Gas (shale gas), forecast that coal remains more significant in proportion until at least mid-century: It is envisaged that coal will continue to provide base load energy up to about 47 GW per annum in 2030, and 59 GW in 2050 (DoE, 2013). Coal is also responsible for high levels of direct and indirect employment in South Africa. Despite an abundant endowment of coal in South Africa, its continued use presents many challenges and its future contribution demands careful stewardship.

Challenges Related to Coal: While the South African economic structure is centred primarily on coal-fired energy and carbon-intensive industries, emissions are to be reduced without compromising socio-economic imperatives. Low coal quality has contributed to Eskom's recent/current energy capacity problems and the high level of emissions are attributable to the mismatch between coal quality and plant design which leads to (ultra) low combustion efficiencies in boilers and gasifiers. In addition, the majority of coal (and power stations) are located in regions relatively far from abundant water supply.

Coal beneficiation includes:

- detailed characterisation of the coal quality and its distribution during exploration (to determine optimal mining and extraction);
- understanding the nature of the coal and its associated contaminating materials directly;
- increasing the efficiency of operation of various conventional washing plants, improvements in the designs of existing plant equipment and the introduction of new processes;
- understanding coal qualities such as particle-size distribution and tonnages of coal output (to select of the most appropriate beneficiation or upgrading technologies);
- matching the quality of coal with a specific utilisation process (in e.g. boilers or gasifiers).

Furthermore, urgent steps are required to reduce GHG emissions, specifically CO_2 from coal consumption while reducing environmental impact, by significantly improving combustion efficiencies and thereby significantly reducing emissions in power generation, process heat production, metallurgical processes and when using coal as a source for valuable carbon-based solid, liquid and gaseous chemicals. These steps include the introduction of clean coal technologies to achieve significantly improved combustion efficiencies, *inter alia*, in power generation and process heat production.

Clean coal technology upgrades for large-scale power plants include changing sub-critical power plants (operating at modest temperatures) to super-critical and ultra super-critical plants (operating at much higher temperatures).

Clean coal technology underway for reducing emissions, increasing efficiencies and providing a source of energy and related products for South Africa include: underground coal gasification, co-firing with biomass, co-generation, conversion of coal-fired boilers to gas, introduction of new "clean coal technology" boiler plant and by utilising hybridisation technologies, such as solar with coal.

Major emission reduction is possible only through carbon mitigation technologies such as carbon capture and storage (CCS). During the utilisation phase, emitted GHG NO_x and SO_x emissions are minimised and CO_2 is captured (pre, during and post-utilisation) and transported to suitable geological sites for injection, storage and monitoring. South Africa recognises and agreed to undertake research into the potential for CO_2 storage.

The bulk of fossil-based energy research in South Africa currently focuses on coal (with some investigations into other fossil fuels) due to coal playing such an important role in the South African economy, as a result of its role as the primary energy source for electricity generation and it being used to produce a substantial proportion of the country's liquid fuels. Coal is also the sole source of metal (iron, steel and ferroalloys) ore reduction.

The utilisation of shale gas is expected to have a significant positive effect on reducing GHGs in South Africa. Research and development is needed if the full potential of shale gas in South Africa is to be exploited. A significant gap is the economic feasibility of the shale gas industry, in terms of the actual volume of shale gas available for extraction and available infrastructure to transport the gas. Currently, research is being conducted on the likely impacts of shale gas activities, yet the coordination of this research is lacking. Of great value would be comprehensive investigations into the baseline environmental conditions which would provide a solid basis for possible litigation action in cases of negative environmental impacts, should the industry be developed. South Africa is in a unique position in that development of the shale gas industry could benefit from the vast amount of international experience available. The opportunity exists to build the industry sustainably.

Fossil fuel research is actively pursued at nine academic institutions in South Africa: Wits, NWU, UWC, Unisa, NMMU, SU, TUT, UP, and UCT. Four industrial partners also reported that they perform, commission and/or fund research in this sector: SANEDI, Sasol, Eskom and the CSIR.

3.6.2 Research Activities and Funding

Table 3.5 highlights R&D activities in this category as reported by survey respondents, and **Figure 3.4** highlights collaborations.

Table 3.5: Fossil energy research sub-fields, outputs and funding by institution

Institution	Field within sector	Key collaborators	Outputs	Funding
Eskom	Clean coal technologies	Coaltech 2020*, IEA Bio Energy, University of Clausthal, *Rheinisch-Westfälisches Elektrizitätswerk (RWE)* – Germany	Reports	Eskom
Eskom	CO_2 abatement	*Ente Nazionale l'Energia Elettrica (ENEL)* – Italy, EON, *Électricité de France (EDF)* – France, ENDW, Doosan, OCTAVIUS (EU Framework Programme – FP7), SA Centre for Carbon Capture and Storage (SA CCS)	Reports	Eskom
Eskom	Coal	NERSA, UCT, Wits, NWU, UP, UKZN, SU, CSIR, SANERI, Coaltech 2020, Sasol, Exxaro, Seoul National University (South Korea), Chonnan, Pennsylvania State University (USA), Nottingham University (UK), Freiberg University (Germany) University of Toulouse (France)	No information	No information
Eskom	Coal characterisation and combustion	Exxaro, Fossil Fuel Foundation, Coaltech 2020, NWU, Anglo Coal, UP, University of Stuttgart (Germany)	3 MSc students Reports Training procedures Coal quality effect model Devolitilisation index	Eskom R4.5 million p.a.
Eskom	Underground coal gasification	Sasol, UWC, UFS, WRC	Reports 30 MW pilot plant operations UCG gas specification UCG commercial business case	Eskom
Eskom	Clean coal technologies including CCS	CSIR, Steinmuller Engineering GmbH-Germany, DNV GL, UCT, Wits, NWU, UWC, Evonik, VGB, The Foundation for Scientific and Industrial Research (SINTEF) – Norway, Netherlands Organisation for Applied Scientific Research (TNO) – Netherlands, *IFP Energies nouvelles* (IFPEN) – France, ENEL, EON, *Électricité de France (EDF)*, Energie Baden-Württemberg (EnBW) – Germany, Doosan, OCTAVIUS (EU FP7), SACCS	Reports	Eskom, EU FP7 R45 000

Table 3.5: Fossil energy research sub-fields, outputs and funding by institution (continued)

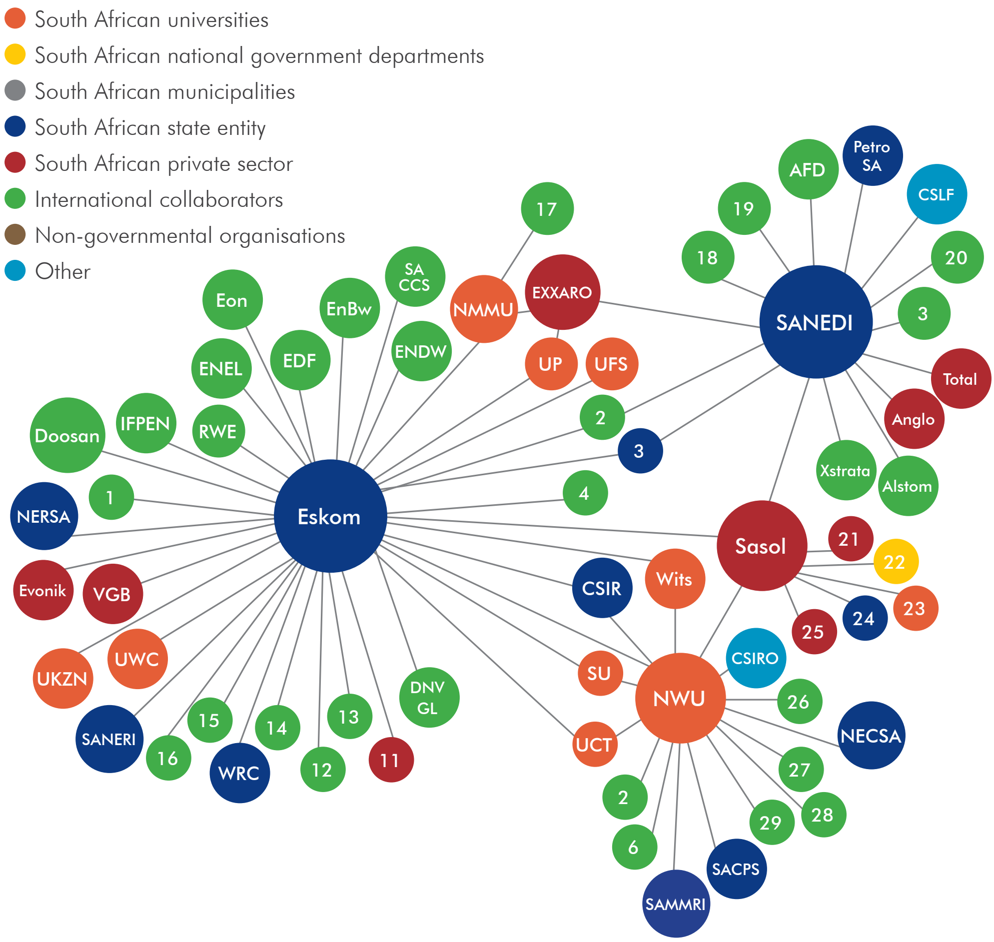
Institution	Field within sector	Key collaborators	Outputs	Funding
NMMU	Biomass-coal composites	Eskom, Exxaro, Hatch-Goba	4 patent applications filed – 1 granted to date	R25 million of which ~R20 million was from DST through TIA. Annual amounts vary (~R6 million p.a.)
NWU	Coal – chemistry, biomass chemistry	Sasol, Pennsylvania State University	18 MSc students 15 PhD students > 80 journal papers > 160 conference papers	Sasol R500 000 p.a., NRF, NWU
NWU	Clean coal technologies	Sasol, Wits, SU, UCT, UP, Pennsylvania State University, University of Freiberg, Imperial College London, University of Twente, Eskom, Petrographics SA, CSIR, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Necsa	25 postgraduate students 60 journal papers 120 conference papers	Sasol R2 million p.a. SARChI (NRF) R1.5 million p.a.
NWU	Coal – environmental monitoring and process improvement (emission control)	Eskom	4 MEng students 2 PhD students 10 journal papers 9 conference papers	Eskom Power Plant Engineering Institute (EPPEI)** R3.5 million p.a.
NWU	Coal – processing and beneficiation	Coaltech 2020, South African Minerals to Metals Research Institute (SAMMRI) – UCT, South African Coal Processing Society (SACPS), Eskom		Coaltech 2020, SAMMRI, SACPS, Eskom R500 000 p.a.
NWU	Modelling and control	No information	New project	THRIP R400 000 p.a.
SANEDI	CCS	Eskom, Sasol, Norwegian Government, World Bank, French Development Agency (AFD), PetroSA, Carbon Sequestration Leadership Forum (CSLF), IEA, Global Carbon Capture and Storage Institute, Exxaro, Total, Anglo, Alstom, Xtrata	No information	South African Centre for Carbon Capture and Storage (SACCCS) membership fee, Sasol R1 million p.a., Eskom R1 million p.a., Norwegian government R1 million p.a., SANEDI R70 000 R1 million p.a. + in-kind, Anglo R100 000 p.a., Xstrata R100 000 p.a., Total R100 000 p.a., PetroSA R100 000 p.a., AFD R100 000 p.a., Exxaro R100 000 p.a., Alstom R100 000 p.a., EU (once off project) R3 million, CSLF (once off project) ~R300 000

Institution	Field within sector	Key collaborators	Outputs	Funding
SANEDI	Shale gas	Eskom, Sasol Syfuel Industry, Norwegian Government, World Bank, French Development Agency, PetroSA – synfuel, Carbon Sequestration Leadership Forum (CSLF) – international ministerial, International Energy Agency, Greenhouse Gas, Global Carbon Capture and Storage Institute, SA/International industry – e.g. Exxaro, Total, Anglo, Alstom, Xtrata	No information	No information
Sasol	Coal-to-liquid and gas-to-liquids technology	Private companies, government, universities, science councils, consultants	Main objectives are to create growth opportunities for the company, as well as support to existing business	Sasol internal funding
Sasol	Gas	Private companies, government, universities, science councils, consultants	Main objectives are to create growth opportunities for the company, as well as support to existing business	Sasol internal funding
UP	Coal – mining	Exarro	No information	No information
UP	Physical asset management	Eskom	No information	No information
Wits	Coal – combustion engineering	Eskom	No information	No information

* *Coaltech 2020 is a collaborative research programme that has been formed by the major coal companies, universities, CSIR, National Union of Mine Workers and the state to address the specific needs of the coal mining industry in South Africa using local and international knowledge and skills.*

** *EPII is a platform for research and postgraduate education between Eskom and South African universities.*

Fossil Fuel Energy



1. University of Clausthal, Germany
2. Coaltech 2020
3. IEA Bio Energy
4. Seoul National University, South Korea
5. Chonnan
6. Pennsylvania State University, USA
7. Nottingham University, UK
8. Freiberg University, Germany
9. University of Toulouse, France
10. Fossil Fuel Foundation
11. Anglo Coal
12. University of Stuttgart, Germany
13. Steinmuller Engineering
14. The Foundation for Scientific and Industrial Research
15. Netherlands Organisation for Applied Scientific Research
16. OCTAVIUS
17. Hatch-Goba
18. Norwegian government
19. World Bank
20. Global Carbon Capture and Storage Institute
21. Private companies
22. South African government
23. South African universities
24. Science councils
25. Consultants
26. University of Freiberg, Germany
27. Imperial College London, UK
28. University of Twente, Netherlands
29. Petrographics South Africa

Figure 3.4: Diagrammatic representation of collaborations between institutes and organisations involved in fossil fuel energy research

3.6.4 Findings and Key Messages

Findings

Most participants reported human resources as being the main limiting factor in terms of their current research capability, with funding being a close second. The funding limitation impacts human resources (both students and professional level supervisors, who cannot be retained) and infrastructure. Due to infrastructure shortcomings, staff and students are sharing very limited space in order to progress with work. Additional infrastructure is urgently required to ensure quality of work and the working environment. Equipment in the fossil fuel sector is also very expensive, therefore research infrastructure is limited and the production rate of research outputs is limited.

Private sector research funders (e.g. Exxaro, Anglo Coal, Sasol, Hatch Goba, Alston, Xstrata, Total, PetroSA) (**Table 3.5**) exceed those in other categories of energy research, but it is reported by respondents that many industry partners have cut down on their funding of research due to financial constraints, which in turn places an enormous strain on academic institutions that rely heavily on industry-generated income. Capacity in the complex mathematical and computational modelling techniques is also very limited.

Most research is reported by Eskom (**Table 3.5**). There is evidence of a significant number of international collaborations (**Figure 3.4**), but none of these seemingly valuable contacts have benefitted researchers at South African universities or resulted in traditional research outputs such as journal papers or student output. The conclusion that can be drawn is that Eskom, although a funder of university research initiatives, conducts its internal research independently of South African research institutions and does not publish its research findings in the open access domain. There is also no indication given of Eskom's investment in fossil fuel research.

Key Messages

There appears to be a lack of understanding of the qualities of coal now available for use in South Africa, and the impact these qualities have on production and use. South Africa is now burning the lowest qualities in the world; qualities that are not compatible with many of the mining, processing and combustion technologies. This leads to low efficiencies and high emissions.

Respondents recommended investment of time and money in the following research fields:

- Coal beneficiation, including:
  - fuel characterisation and assessment: establishment of a performance and testing function to support optimisation of existing coal plant thermal efficiency; online coal quality impact monitoring; real time coal analysis; predicting coal quality impacts;
  - future fossil fuel conversion technologies;
  - wet to dry coal optimisation; dry processing of fines;
  - fines/discard dump utilisation.
- Combustion and gasification, including:
  - fluidised-bed combustion and combustion characterisation;
  - underground coal gasification (UCG).
- Characterisation of untapped coal reserves to ensure clean usage; alternative coalfields; gas – scanning developments nationally and locally for business viability.

- Emission reduction including carbon abatement by the introduction of new clean coal technologies.
- The South African Centre for Carbon Capture and Storage (SACCCS) is conducting a large-scale CO_2 test injection project, with the intention of undertaking a pilot injection hole by 2017 in one of two locations on shore in South Africa. Additional research is also being undertaken in various universities to test unconventional methods of CO_2 storage. Using captured CO_2 has potential for enhanced coalbed methane recovery in coalbed methane-rich fields in the region. It is currently generally believed that emphasis should rather be placed on larger scale CO_2 storage.
- Investigation of the 6 000 other industrial users of coal in the country is needed.
- Co-firing coal, gas and biomass.
- Co-generation (use of waste heat in the coal-fired plant).
- Increased efficiency in production and use.

Eskom specifically suggested investigation of the following from an industry perspective: UCG national research strategy for the country, optimised combined electricity/chemical production, hydrogen enrichment for transport solutions, coalbed methane, shale gas, methane hydrate, national gas infrastructure, gas storage and transport. There is also a significant need within Eskom, for better control in their processes, which also requires an improved analysis of their streams in terms of composition and process parameters.

3.7 Energy Efficiency and Storage in South Africa

3.7.1 Introduction

Energy Efficiency

Energy efficiency (EE) is a measure of the saving of energy used to produce goods and services while maintaining desired benefits. Improved energy efficiency can reduce the energy intensity of the SA economy which to date is one of the highest in the world due to the inefficient use of coal-based electricity – this in turn makes our economy uncompetitive. EE has the ability to postpone or delay very costly investment in new generation capacity but most of all, against the background of the increases in electricity prices in SA, it will save money for various economic sectors.

According to the 2003 White Paper on Renewable Energy (DME, 2003), expenditure on energy constitutes about 15% of South African GDP. Therefore, energy storage and energy efficiency are important facets of integrated energy planning.

Policy Framework

The Energy Efficiency policy framework is defined in:

- 1998: The White Paper on Energy in the Republic of South Africa, issued by the former Department of Minerals and Energy (DME), promotes EE and energy conservation.
- 2004: The Regulatory Policy on Energy Efficiency and Demand Side Management (EEDSM) for the South African electricity industry was issued by the National Electricity Regulator (NERSA), providing the mechanisms for access to EEDSM funding, administration of funds, development of EEDSM plans, obligations of EEDSM implementation, EEDSM awareness raising, etc.

- 2005: The National Energy Efficiency Strategy (revised in 2008 and 2012), emhasises the urgent need to solve the energy security problem through EEDSM. A national target of 12% EE improvement by 2015 was set.
- 2010: The DoE published a policy framework document to support EEDSM for the electricity sector, which empowers NERSA to regulate and set the funding level for EEDSM.

Eskom leads the main EE programme (the EEDSM Programme), with implementation financing being obtained mainly through electricity tariffs (de la Rue du Can *et al.*, 2013). The programme introduces tax allowances for EE in Sections 12I and 12L of the Income Tax Act of 1962 as incentives for energy conservation. According to the regulation energy savings reports have to be compiled by registered measurement and verification bodies which are accredited by the South African National Accreditation System (SANAS). Until 2012 a total of 3 072 MW had been saved since the implementation of their Integrated Demand Management programmes (Eskom, 2012).

Supporting programmes for EE improvements include:

Table 3.6: Programmes supporting energy efficiency

Mechanism	Fund/mechanism/target	EE initiative
Public Sector Support	R600 million	Municipal infrastructure
Manufacturing Upgrade Support	R5.75 billion	Manufacturing enterprises for plant upgrade, job creation, increase of competitiveness, value-add process support and green technologies
Green Energy Efficiency Fund	Soft loans (prime rate 2%) of up to R20 million	Qualifying EE investments
Residential Mass Rollout		Replacement of inefficient lighting, implementation of energy saving technologies and load control devices
Solar Water Heating (SWH) and Heat Pumps	Rebates provided by Eskom. Targets were 1 million SWH and 65 500 heat pumps	Households
Tax Incentives	Section 12L of the Income Tax Act	Both industries and individuals can apply for an energy efficiency allowance from taxable income on the basis of energy efficiency savings

The major fields of research include: energy management, energy efficient technologies, efficient lighting, energy planning, customer and energy research, fuel cells, batteries, energy storage.

Participants reported that even though the EEDSM initiatives are well conceptualised and financially supported, there appears to be a lack of adoption and commitment from the public due to *inter alia* a general lack of consumer awareness and understanding of energy efficiency. There is an even higher potential for energy savings in the industrial and commercial sectors.

Respondents reported a number of factors inhibiting the uptake of energy efficiency improvements, including:

- a lack of appropriate and effective incentives for the participation in energy efficiency initiatives;
- a lack of energy data;
- a lack of effective decision-making in terms of incentives measures and supporting models to quantify the cost and impact of incentives to the economy;
- inadequate coordination mechanisms.

Energy Storage

In an electrical power grid, e.g., energy is stored during times when production (from power plants) exceeds consumption and the stores are used at times when consumption exceeds production. Due to the intermittent nature of some renewable energy sources, energy storage is of particular importance in renewable energy systems. Energy storage methods can be broadly categorised as electrical, chemical, mechanical, electrochemical, biological and thermal.

Electrical storage is central to addressing the peak demand profile of the country. R&D initiatives are attempting to address the life-cycle cost aspects of a variety of battery options (NiMh, Lithium, NaS/NaNiCl, Lead-acid, Zinc-bromine, V-redox-flow), and the next five years should be used to identify the potential role of the South African R&D community in this space; at both the basic and applied levels.

Some challenges relating to energy storage include:

- Technological – despite improved technologies, evaluation of life-cycle costs are needed to show long-term economic benefit for each technology.
- Market and regulatory issues – there is a need to create appropriate market signals to incentivise the building of storage capacity and provision of storage services.
- Strategic issues which include the development of a systemic or holistic approach to storage, bridging technical, regulatory, market and political aspects.
- The future of the CO_2 emissions framework, public acceptance of cables, grid access and investment priorities also present challenges to storage development.
- The main challenge for energy storage development is economic. The economic and business case varies from case to case, depending on where the storage is needed: generation, transmission, distribution or customer level. The benefits for users/operators are also closely linked to the question of storage location. A number of uncertainties strongly affect the value assessment of energy storage:
  - › The existence of compensation schemes for storage.
  - › The potential to develop new and innovative business models.
  - › Ownership of the future energy storage systems.
  - › Grid integration.
  - › Large centralised and small decentralised storage.
- Flexible generation systems (centralised and decentralised).

3.7.2 Research Activities and Funding

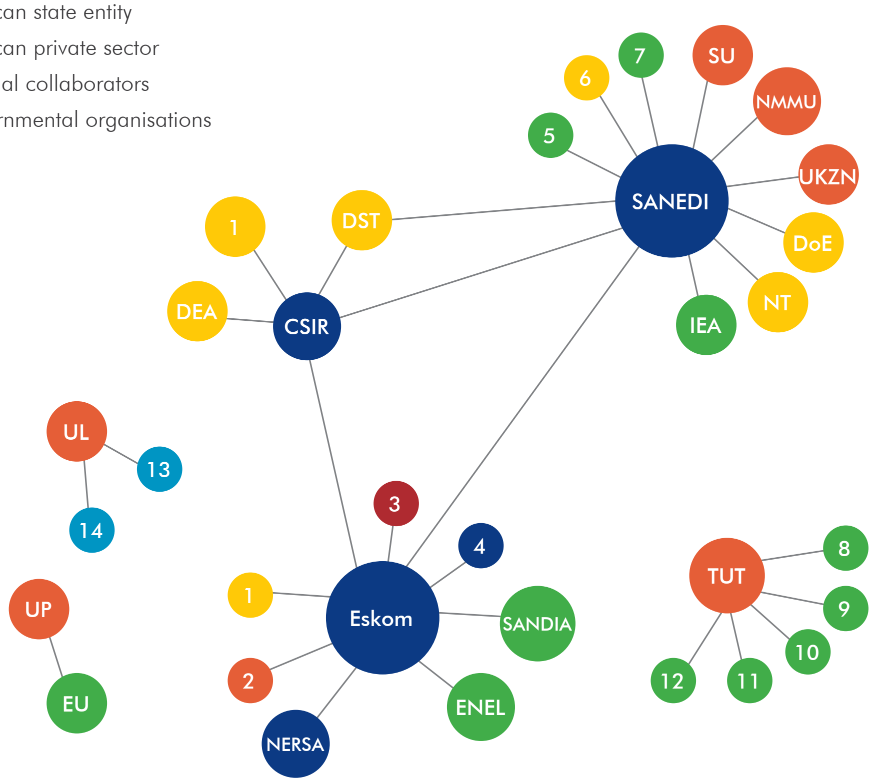
Table 3.7 highlights research and development reported by respondents in this category, and **Figure 3.5** highlights collaborations.

Table 3.7: Energy storage and efficiency sub-fields, outputs and funding by institution

Institution	Field within sector	Key collaborators	Outputs	Funding
CSIR	Electrochemical storage	Government, DST, DEA, Eskom	Postgraduate students Journal papers Conference papers Reports Patents	No information
Eskom	Energy efficiency	Government, universities, SANEDI, CSIR, NERSA, Battery SA, National ESA, Sandia National Laboratories, ENEL	No information	NERSA
NWU	Energy efficiency and energy storage	No information	2009–2013: 20 Masters students 10 PhD students 60 journal papers 100 conference papers	Sasol R2 million p.a. SARChI (NRF) R1.5 million p.a.
SANEDI	Chemical storage, thermal energy storage	Algal Bio Energy platform (ABP), eThekwini Municipality, Biojet working group, SU, NMMU, UKZN, CSIR, DST, DoE, Eskom, National Treasury (NT), IEA	University research outputs through funded and demonstrable pilot projects	N/A since funding is often leveraged or joint funding agreements with another funder/industry are entered into.
TUT	Energy efficiency and energy storage	University of Tokyo, Key Laboratory of Applied Superconductivity, (Beijing China), Russian Scientific R&D Cable Institute (Moscow, Russia),Western Michigan University (USA), University of Madras (India)	8 MSc students 5 PhD students 15 journal papers 30 conference papers	GIZ – Energy efficiency R70 000, GIZ – Energy storage R10 000
UL	Electrochemical storage, computational modelling of energy storage materials	Electrochemical storage; academic institutions (local and international), public industry (local and international)	In the last 5 years, 4 students have converted from MSc to PhD, 1 PhD student 2 postdoctoral researchers 8 journal papers 1 book chapter 9 conference papers	No information
UP	Chemical storage, thermal energy storage	EU partners	No information	NRF/SARChI Chairs R500 000, SA Water and Energy Forum (WEF) R150 000

Energy efficiency and storage

- South African universities
- South African national government departments
- South African municipalities
- South African state entity
- South African private sector
- International collaborators
- Non-governmental organisations
- Other



1. South African government
2. South African universities
3. Battery South Africa
4. National Electrical Safety Authority
5. Algal Bio-Energy platform
6. eThekweni Municipality
7. Biojet working group
8. University of Tokyo, Japan
9. Key Laboratory of Applied Superconductivity, China
10. Russions R&D Cable Institute
11. Western Michigan Universitt, USA
12. University of Madras, India
13. Local and international academic institutions
14. Local and international public industry

Figure 3.5: Diagrammatic representation of collaborations between institutes and organisations involved in fossil energy efficiency and storage research

3.7.3 Key Messages

- Government and other stakeholders should (continue to) play an important role in the deployment of energy efficiency strategies and measures.
- There is a lack of commitment to and adoption of energy efficient measures. This issue can be resolved by improving awareness and understanding of energy efficiency and implementing effective incentives for the participation of the energy saving drive.
- More stringent legislation needs to be implemented to drive energy efficiency together with incentive schemes.
- Financing needs to be adequately available for the implementation of incentives.
- Energy storage is not considered in the IRP 2010 (except for pump storage schemes); the support and promotion of research and development on energy storage and efficiency and policy frameworks to accommodate the need and importance of energy storage in South Africa should be a priority.

4 Bibliometric Study

The bibliometric study focused on all forms of energy research published in peer-reviewed scientific journals by HEIs, as well as other organisations in South Africa. The Centre for Research on Science and Technology (CREST) was commissioned by ASSAf to undertake this work and this chapter presents their report (CREST, 2014). The current report has included statistics on publications in Nuclear Physics as well as in Electrochemistry which are not always directly related to energy and which may not be relevant to this study. However, given the limited scope of this study and time constraints, the unrelated publications have not been removed.

4.1 Introduction

The bibliometric analysis was conducted on a "core" dataset (Web of Science [WoS] subject categories as below) and a "core plus" dataset that includes additional South African (SA) energy papers. The core dataset allows for international comparisons (including citation analyses), as it includes only papers within the standard subject category classifications of journals in the WoS. Altogether five subject categories were included (as per the ASSAf brief) for producing the "core" dataset, namely:

Table 4.1: Subject categories used to define the "core" dataset of the bibliometric analysis

Subject category	Focus
Energy & Fuels	Non-nuclear energy
Electrochemistry	
Petroleum Engineering	
Nuclear Science & Technology	Nuclear energy
Nuclear Physics	

Analyses were produced based on the following list of indicators for the period 2000–2011 (a 12-year period was selected to provide as long a period as possible so as to ascertain trends):

1. Total number of SA energy papers by year (both "core" and "core plus" datasets).
2. Total number of SA energy papers by subject category (both "core" and "core plus" datasets).
3. Total number of energy papers by SA institutions (both "core" and "core plus" datasets).
4. Total number of energy papers by SA sectors (both "core" and "core plus" datasets).
5. Total number of SA energy papers by author (both "core" and "core plus" datasets).
6. Most frequently occurring countries of collaboration in SA energy papers, by subject category (both "core" and "core plus" datasets).
7. Citation impact of SA energy papers.

4.2 Methodology

A database of SA energy papers was compiled in the following manner. First, five journal subject categories from the WoS were taken as providing sufficient coverage of both nuclear and non-nuclear energy research in SA. These subject categories are:

- Energy & Fuels, which covers resources on the development, production, use, application, conversion, and management of non-renewable (combustible) fuels (such as wood, coal, petroleum, and gas) and renewable energy sources (solar, wind, biomass, geothermal, hydroelectric).
- Electrochemistry, which covers resources that deal with the chemical changes produced by electricity and the generation of electricity by chemical reactions. Applications include dry cells, lead plate, storage batteries, electroplating, electrode position (electrolysis), purification of copper, production of aluminium, fuel cells, and corrosion of metals, as well as metallurgical aspects.
- Petroleum Engineering, which covers resources that report on a combination of engineering concepts, methods, and techniques on drilling and extracting hydrocarbons and other fluids from the earth (e.g. chemical flooding, thermal flooding, miscible displacement techniques, and horizontal drilling) and on the refining process. Relevant topics in this category include drilling engineering, production engineering, reservoir engineering, and formation evaluation, which implies reservoir properties through indirect measurements.
- Nuclear Science & Technology, which covers resources on nuclear energy (fission and fusion processes), nuclear energy and fuel, nuclear power, and nuclear electric power generation. This category also includes resources on nuclear engineering (the branch of technology that applies the nuclear fission process to power generation), nuclear safety, radiation effects, and radioactive waste management.
- Nuclear Physics, which includes resources on the study of nuclear structure, decay, radioactivity, reactions, and scattering. Resources in this category focus on low-energy physics.

It should be noted that any journal in the WoS can be assigned to more than one subject category. Thus, by extracting all papers (with at least one SA country address) appearing in journals in any of the above five subject categories, other subject categories (e.g. thermodynamics) also emerged.

In addition to the above "core" dataset, which included all SA papers in the five selected subject categories, more relevant papers were identified by means of a follow-up strategy, and added to the "core" dataset. The follow-up strategy consisted of the following:

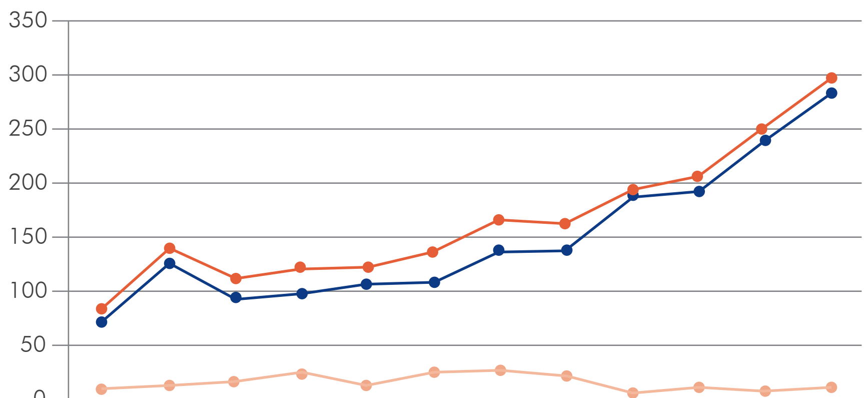
- Searching for additional WoS papers (i.e. papers not covered by the five WoS subject categories) by extracting all articles with the word "energy" in either the title, journal name, author address or article keywords.
- Searching a database of SA papers for articles with the word "energy" in the title or keywords.
- Searching the *Journal of Energy in Southern Africa* for papers that included at least one author with a SA affiliation.

The above strategies resulted in another 194 papers being identified as belonging to the field of energy research. The "core plus" database therefore consisted of 1 965 papers (i.e. 1 771 from the "core" dataset and 194 additional papers).

4.3 Results

4.3.1 Total Number of SA Energy Papers by Year (both "core" and "core plus" datasets)

The trend in output of the two categories of papers described in Section 4.2, as well as the aggregate number, is presented in **Figure 4.1**. It clearly shows that there has been a steady increase in SA's publication output over the 12-year period, with an overall growth of 257% in output over the period. Although this growth occurred from a small base (only 82 papers in 2000), the increase has been relatively steady and consistent, culminating in the production of 293 papers in 2011. The average annual growth rates for the aggregate and the two categories of papers separately are as follows: 9.8% ("All"), 11.1% ("4 WoS SC") and -4.5% ("Additional").



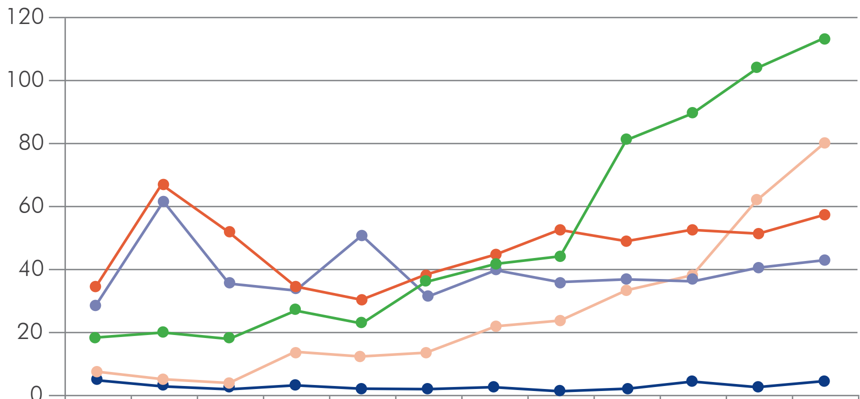
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
All (a+b)	82	139	110	122	120	134	165	161	191	202	246	293
5 Wos SC (a)	71	125	94	98	106	108	137	137	188	189	237	281
Additional (b)	11	14	16	24	14	26	28	24	3	13	9	12

Figure 4.1: South African energy papers, by data source and by year (2000–2011)

Note: "5 WoS SC" refers to the following five subject categories in the WoS: (1) Electrochemistry; (2) Energy & Fuels; (3) Petroleum Engineering; (4) Nuclear Science & Technology; and (5) Nuclear Physics.

4.3.2 Total Number of SA Energy Papers by Subject Category (both "core" and "core plus" datasets)

The general trend in overall output presented in Section 3.3.1 masks rather significant differences when the output is disaggregated by subject category. Two fields – Electrochemistry and Energy & Fuels – recorded the largest and most consistent increases in output (with average annual growth rates of 30.6% and 20.8%, respectively). In fact, in both cases, output started increasing very steeply over the past five years (**Figure 4.2**). The output in the other three categories remained basically unchanged with no or very little growth.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Electrochemistry	7	4	3	13	12	13	21	23	33	38	62	80
Energy & Fuels	18	20	18	27	23	37	41	44	82	90	105	114
Petroleum Engineering	5	3	2	3	1	1	2	0	1	4	2	4
Nuclear S&T	28	62	36	33	51	31	41	35	37	37	41	43
Nuclear Physics	34	67	52	34	30	38	44	52	49	53	51	57

Figure 4.2: South African energy papers compiled from the five selected WoS subject categories, by subject category and by year (2000–2011)

Note: The average annual growth rates for the period 2000–2011 are as follows: Electrochemistry (30.6%), Energy & Fuels (20.8%), Petroleum Engineering (-2.1%), Nuclear S&T (0.3%) and Nuclear Physics (2.5%).

The WoS assigns journals to one or more categories depending on whether these are viewed as single-discipline or multidisciplinary (even trans-disciplinary) journals. It is therefore quite often the case that a particular journal can be classified into as many as three or four subject categories. This certainly applies to the case of energy research which spans a number of disciplines. In **Figure 4.3** the breakdown of the papers (n=1 771) that appeared in the WoS journals by subject category is presented.

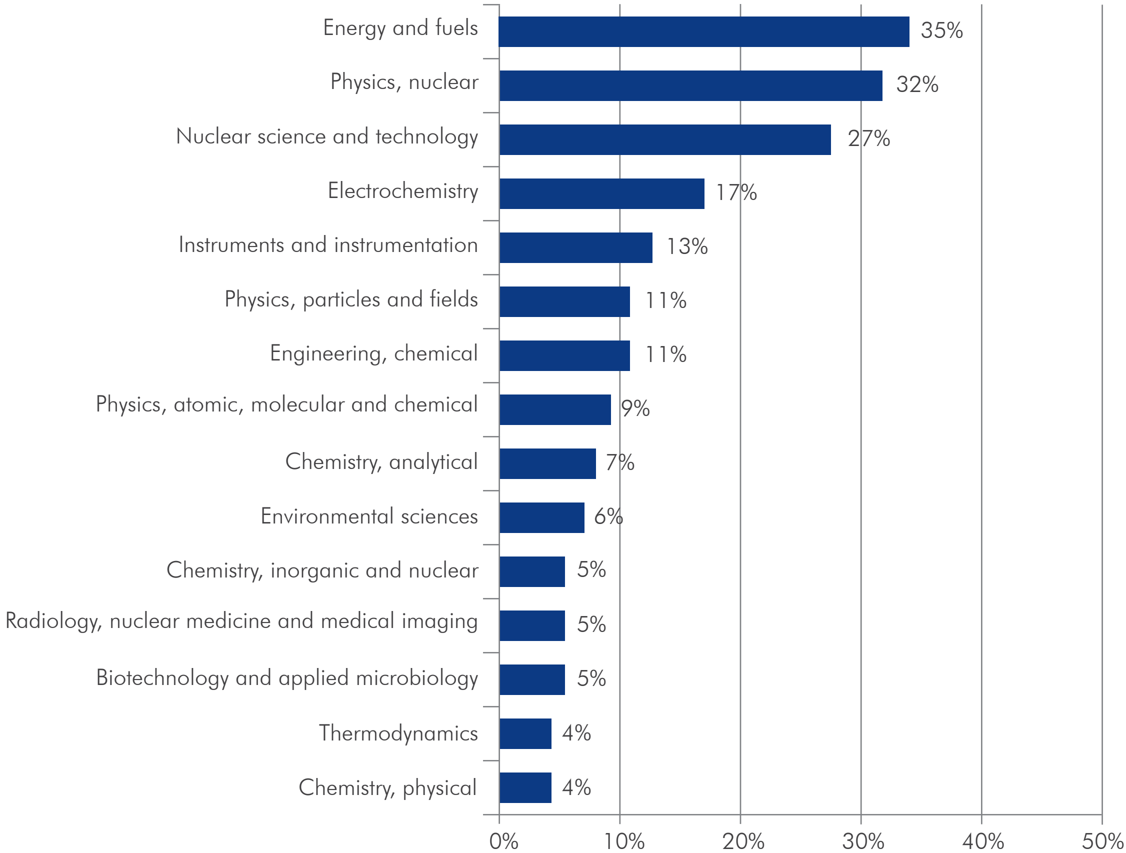


Figure 4.3: WoS journal subject category distribution (%) of energy papers (n=1 771, 2000–2011)

Note: Only papers within the five selected WoS subject categories have been considered. More than five categories are listed here because of multiple subject classifications of journals.

4.3.3 Total Number of Energy Papers by SA Institutions (both "core" and "core plus" datasets)

The production of scientific papers produced over the past 12 years in this area in SA has been dominated by five institutions: UCT, SU, Wits, iThemba LABS and UP (**Table 4.2**). These five institutions together produced nearly two-thirds (65%) of the total output. Other significant contributions were made by NWU, UWC, RU and CSIR.

A breakdown by time period reveals some interesting trends:

- Although UCT produced the overall largest proportion of output of 18%, its contribution in the most recent period declined slightly to 15%. SU, whose total share over the whole period constitutes 13%, managed in the most recent period to equal UCT's share (15%).
- The relative proportions of Wits and iThemba LABS have declined over the total period, although they remain significant contributors to the overall production.
- Conversely, UWC, NWU and CSIR have recorded noticeable increases in their relative contributions to papers in these fields.
- UP's share of total output in this field has remained quite consistent over the total period.

Table 4.2: Top-25 SA organisations responsible for energy papers, by year period

Organisation	Total period: 2000–2011 (% of 1 965 papers)	Period 1: 2000–2003 (% of 453 papers)	Period 2: 2004–2007 (% of 580 papers)	Period 3: 2008–2011 (% of 932 papers)
UCT	18% (346)	18% (80)	21% (124)	15% (142)
SU	13% (261)	13% (61)	10% (58)	15% (142)
Wits	12% (231)	17% (76)	11% (62)	10% (93)
iThemba LABS	12% (228)	14% (62)	14% (80)	9% (86)
UP	10% (195)	9% (43)	11% (62)	10% (90)
NWU	8% (161)	6% (29)	7% (41)	10% (91)
UWC	7% (130)	3% (12)	4% (21)	10% (97)
RU	6% (122)	3% (13)	10% (56)	6% (53)
CSIR	5% (102)	1% (5)	4% (24)	8% (73)
UKZN	4% (86)	5% (24)	4% (24)	4% (38)
Sasol	4% (82)	3% (12)	5% (27)	5% (43)
UJ	3% (65)	4% (16)	3% (17)	3% (32)
Necsa	3% (51)	3% (15)	2% (9)	3% (27)
TUT	3% (51)	<1% (2)	2% (10)	4% (39)
Unisa	2% (48)	4% (19)	2% (12)	2% (17)
CPUT	2% (38)	<1% (2)	1% (7)	3% (29)
NMMU	2% (37)	1% (6)	2% (13)	2% (18)
UZ	2% (30)	4% (16)	1% (7)	1% (7)
PBMR	1% (28)	<1% (2)	1% (8)	2% (18)
UFS	1% (22)	1% (6)	1% (7)	1% (9)
VUT	1% (16)	0% (0)	<1% (1)	2% (15)
UL	1% (15)	2% (9)	1% (3)	<1% (3)
UFH	1% (13)	<1% (2)	1% (3)	1% (8)
UNIVEN	1% (11)	<1% (1)	<1% (2)	1% (8)
DUT	<1% (9)	1% (3)	<1% (1)	1% (5)

Note: All papers have been considered (i.e. papers within the five selected WoS subject categories, as well as additional papers).

4.3.4 Total Number of Energy Papers by SA Sectors (both "core" and "core plus" datasets)

Three sectors were identified as contributing to scientific papers in energy in SA: the university sector, the science council sector (CSIR, iThemba LABS) and other (e.g. Necsa, Sasol and PBMR). Perhaps not unexpectedly, the university sector dominates output and – as **Figure 4.4** shows – also increasingly so; their share increased from 83% to 88% in the most recent period.

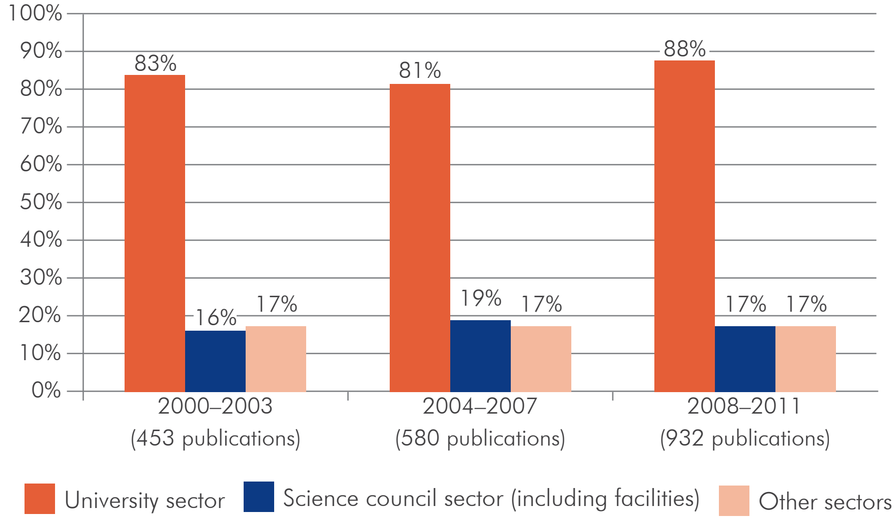


Figure 4.4: Sector distribution (%) of South African energy papers, by year period

Note: Percentages do not add to 100% in any year period because of multiple co-authorship. All papers have been considered (i.e. papers within the five selected WoS subject categories, as well as additional papers).

4.3.5 Total Number of Energy Papers by SA Author (both "core" and "core plus" datasets)

Table 4.3 lists the 20 most productive SA authors in energy research, where a SA author is taken to mean an individual with a SA address in the papers produced. As can be seen, seven of the 20 authors are affiliated with iThemba LABS. The remainder are affiliated with SA universities.

Table 4.3: Twenty most productive SA authors of energy papers (2000–2011)

Authors	Institutions	Number of papers	% of 1965 papers
Nyokong, T	RU, Department of Chemistry	70	4%
Ozoemena, KI	UP, Department of Chemistry/CSIR	59	3%
Steyn, GF	iThemba LABS	43	2%
Cleymans, J	UCT, Department of Physics	42	2%
Iwuoha, EI	UWC, Department of Chemistry, SensorLab	42	2%
Lawrie, JJ	iThemba LABS	37	2%
Smit, FD	iThemba LABS	36	2%
Connell, SH	UJ	31	2%
Waanders, FB	NWU, School of Chemical & Minerals Engineering	30	2%
Fortsch, SV	iThemba LABS	29	1%
Van der Walt, TN	CPUT, Faculty of Applied Sciences	27	1%
Ebenso, EE	NWU, Faculty of Agriculture, Science & Technology, Material Science Innovation & Modelling (MaSIM) Research Focus Area	26	1%
Fearick, RW	UCT, Department of Physics	25	1%
Bharuth-Ram, K	DUT	23	1%

Table 4.3: Twenty most productive SA authors of energy papers (2000–2011) (continued)

Authors	Institutions	Number of papers	% of 1965 papers
Przybylowicz, WJ	iThemba LABS, Materials Research Department/ *Akademia Górniczo-Hutnicza* (AGH) University of S&T, Faculty of Physics & Applied Computer Science, Poland	22	1%
Cowley, AA	SU, Department of Physics	21	1%
Van Dyk, EE	NMMU	20	1%
Mullins, SM	iThemba LABS	20	1%
Neveling, R	iThemba LABS	20	1%
Comins, JD	Wits, School of Physics	19	1%

4.3.6 Most Frequently Occurring Collaborating Countries in SA Energy Papers by Subject Category (both "core" and "core plus" datasets)

An analysis was undertaken to establish which countries contribute most, in terms of co-authorship, to the production of SA energy papers. **Table 4.4** and **Table 4.5** give the relative contributions of the Top-10 collaborating countries as a percentage of all SA energy papers, not only co-authored papers. **Table 4.4** shows that, whereas Germany initially assumed the first position in 2000–2003 (13%), it was overtaken by the United States of America (USA) in 2004–2007 (13%). Although the USA maintained its lead in 2008–2011, the size of its relative share subsequently declined (from 13% to 8%). China is growing in prominence as a collaborating country for SA energy research. Although China does not feature in the list of the Top-10 co-authoring countries in either the 2000–2003 or 2004–2007 periods, it occupies the third position in the list for the most recent period (2008–2011).

Table 4.4: Top-10 collaborating countries of energy papers, by year period

Total period: 2000–2011 (% of 1 965 papers)		Period 1: 2000–2003 (% of 453 papers)		Period 2: 2004–2007 (% of 580 papers)		Period 3: 2008–2011 (% of 932 papers)	
Country	Share	Country	Share	Country	Share	Country	Share
USA	10% (203)	Germany	13% (58)	USA	13% (74)	USA	8% (79)
Germany	9% (179)	USA	11% (50)	Germany	10% (57)	Germany	7% (64)
UK	6% (118)	UK	8% (36)	UK	6% (35)	China	7% (63)
France	4% (80)	France	4% (17)	France	4% (26)	UK	5% (47)
China	4% (75)	Poland	3% (14)	Poland	4% (25)	Nigeria	5% (43)
Italy	3% (67)	Belgium	3% (13)	Italy	4% (24)	France	4% (37)
Netherlands	3% (57)	Italy	3% (13)	Japan	3% (17)	India	4% (33)
Poland	3% (55)	Russia	3% (13)	Netherlands	3% (17)	Netherlands	3% (31)
Japan	3% (52)	India	2% (10)	Switzerland	3% (16)	Italy	3% (30)
India	3% (50)	Switzerland	2% (10)	Belgium	3% (16)	Australia	3% (29)
Nigeria	3% (50)						

Note: All papers have been considered (i.e. papers within the five selected WoS subject categories, as well as additional papers).

In terms of the individual subject categories (**Table 4.5**), Electrochemistry has a markedly different collaboration profile than those of the other subject categories. It is not dominated by the USA or Germany as main collaborating country, but by Nigeria and China.

Table 4.5: Top-10 collaborating countries of energy papers, by WoS subject category (2000–2011)

Electrochemistry (% of 309 papers)		Energy & Fuels (% of 619 papers)		Nuclear S&T (% of 475 papers)		Nuclear Physics (% of 561 papers)	
Country	Share	Country	Share	Country	Share	Country	Share
Nigeria	8% (26)	USA	8% (52)	Germany	14% (66)	Germany	20% (112)
China	6% (19)	UK	5% (29)	USA	13% (62)	USA	17% (98)
France	4% (11)	India	3% (17)	UK	7% (31)	Italy	9% (51)
Saudi Arabia	3% (10)	Canada	2% (13)	France	6% (28)	China	9% (50)
India	3% (9)	Germany	2% (13)	Belgium	5% (23)	UK	9% (50)
Belgium	3% (9)	China	2% (12)	Poland	5% (22)	France	8% (46)
UK	3% (8)	Australia	2% (11)	Netherlands	4% (21)	Poland	8% (44)
Australia	2% (5)	Netherlands	2% (11)	Italy	4% (20)	Japan	7% (41)
Chile	2% (5)	Nigeria	1% (9)	Hungary	4% (19)	Russia	6% (35)
Ireland	2% (5)	Malaysia	1% (8)	Switzerland	4% (17)	Switzerland	6% (32)
Portugal	2% (5)						
Romania	2% (5)						

Note: Only papers within the five selected WoS subject categories have been considered. The category of Petroleum Engineering is excluded as there are only 28 papers in this category.

Table 4.6 presents the shares of the different world regions to the overall production of energy research papers by SA authors. Notably, three regions dominate as collaborators: Europe (30% of all papers), North America (11%) and Asia (10%). That being said, Europe's contribution has been consistently declining (from 36% in 2000–2003 to 26% in 2008–2011), whereas that of Asia has increased (from 5% in 2000–2003 to 14% in 2008–2011).

Table 4.6: World region classification (%) of collaborating countries of South African energy papers, by year period

Region	Total period: 2000–2011 (% of 1 965 papers)	Period 1: 2000–2003 (% of 453 papers)	Period 2: 2004–2007 (% of 580 papers)	Period 3: 2008–2011 (% of 932 papers)
Southern Africa Development Community (SADC)	1% (15)	<1% (2)	1% (4)	1% (9)
Rest of Africa	4% (77)	<1% (2)	2% (9)	7% (66)
South and Central America and the Caribbean	1% (26)	<1% (2)	1% (7)	2% (17)
North America	11% (224)	11% (52)	14% (80)	10% (92)
Europe	30% (582)	36% (161)	31% (182)	26% (239)
Asia	10% (189)	5% (23)	6% (33)	14% (133)
Middle-East	1% (18)	2% (7)	1% (4)	1% (7)
Australia and Oceania	3% (53)	1% (6)	3% (16)	3% (31)

Note: All papers have been considered (i.e. papers within the five selected WoS subject categories, as well as additional papers).

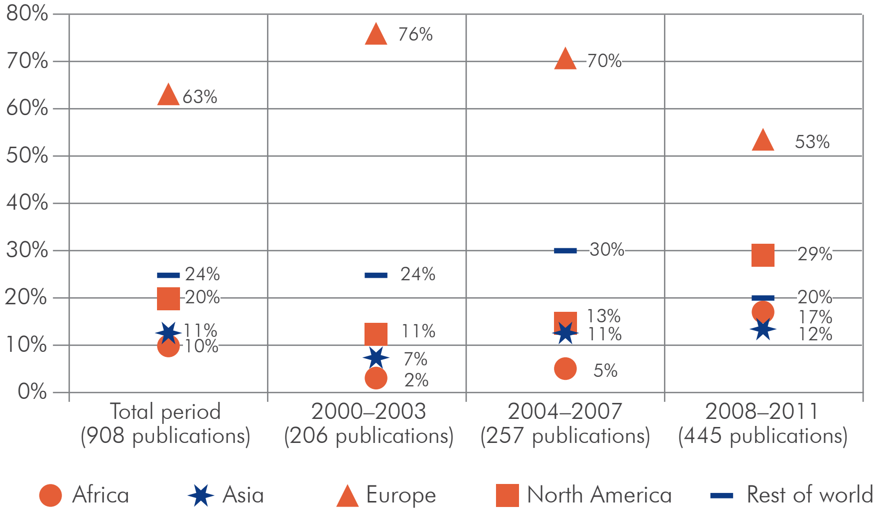


Figure 4.5: World region classification (%) of collaborating countries of internationally co-authored SA energy papers, by year period

Note: Percentages do not add to 100% in any year period because of multiple co-authorship. All papers have been considered (i.e. papers within the five selected WoS subject categories, as well as additional papers).

Figure 4.5 presents the subset of internationally co-authored papers (908 in total), as opposed to all papers, and provides a breakdown of these in terms of the world region of the international collaborators. In 2000–2003, 76% of all internationally co-authored papers included a European collaborator. This figure has subsequently declined to 70% in 2004–2007 and 53% in 2008–2011. At the same time, a significant increase can be observed for Asian co-authors (from 11% of all internationally co-authored papers in 2000–2003, to 29% in 2008–2011).

The high degree of collaboration that emerged from the analysis above is also reflected in the co-authorship patterns of individual papers. For this purpose, three categories of authorship are identified: papers with authors from the same SA institution; papers with more than one author (but from at least two SA institutions) and papers with more than one author (where at least one of the authors is from a foreign institution).

The results show that multiple authorship is, and has been, the norm in this field, with small percentages of single-authored papers (**Figure 4.6**). In fact, the number of single authorship papers declined from 18% in the earliest period to 8% in the most recent period. It is also significant that international co-authorship is the most prevalent and again shows a steady increase, to the extent that nearly 50% of all papers in this field over the past three years involved authors from overseas institutions.

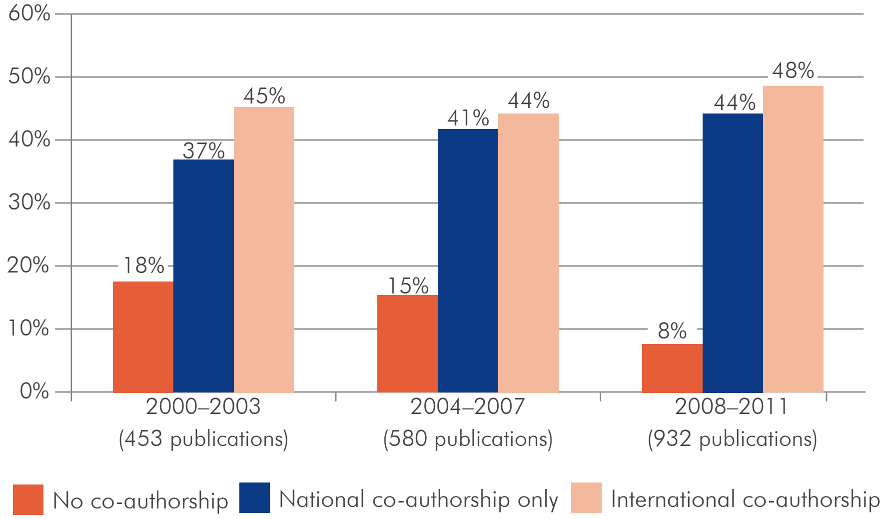


Figure 4.6: Nature of co-authorship of South African energy papers, by year period

Note: All papers have been considered (i.e. papers within the five selected WoS subject categories, as well as additional papers).

When co-authorship is disaggregated by subject category, a more nuanced picture emerges (**Figure 4.7**). International co-authorship of papers in the field of Nuclear Physics is the most dominant, with nearly three in every four papers involving foreign authors. In the sub-fields of Electrochemistry and Energy & Fuels, however, national collaborations are clearly more common.

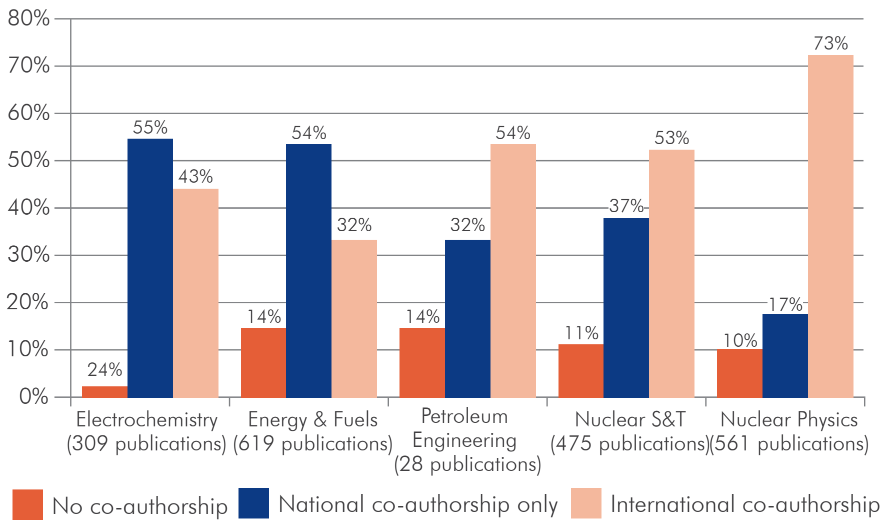


Figure 4.7: Nature of co-authorship of South African energy papers, by WoS subject category (2000–2011)

Note: Only papers within the five selected WoS subject categories have been considered.

4.3.7 Citation Impact of SA Papers in Energy Research

Data provided by the Centre for Science and Technology Studies (CWTS) at the University of Leiden allowed the calculation of the citation impact (or visibility) of the 1 711 SA authored papers. **Table 4.7** presents information on the visibility/impact of this dataset using the mean normalised citation score (MNCS) as calculated by the University of Leiden.

The MNCS is a normalised indicator derived from the mean citation score (MCS). The MCS gives the average number of citations of the papers of a particular unit/category. However, a shortcoming of the MCS indicator is that it does not take into account differences between papers from different subject categories (i.e. different scientific fields), different document types (e.g. articles *versus* reviews) and papers of different ages (i.e. older *versus* newer papers). A more sophisticated indicator of citation is the MNCS, which performs a normalisation to correct for papers from different subject categories and of different document types and ages. The MNCS also enables the determination of the performance of a unit/category; i.e. whether it is significantly far below (indicator value < 0.5); below (indicator value 0.5–0.8); about average (0.8–1.2); above (1.2–2.0); or far above (>2.0) the world average.

The salient results as presented in **Table 4.7** are the following:

- The overall field-normalised citation score for the SA papers in energy research is 0.89, which means that the average visibility and impact of these papers is comparable to the world average for the field. This is a positive result as it means that these papers receive recognition from other scholars working in the same field commensurate with most papers published in the world in the field of energy research.
- It is even more interesting, and not surprising, that the MNCS for internationally co-authored papers equals 1.00. Within this subset, those papers which were co-authored with scientists in other SADC countries (1.98)[5], North America (1.24), the Middle-East (1.22) and Asia (1.14) recorded above world average field-normalised scores. The table also demonstrates a generally accepted principle of scientific publishing, *viz*. that papers that are more local (and which involve national co-authorship only) rarely generate high citation impact.

Table 4.7: Mean normalised citation score (MNCS) of SA energy papers, by nature of co-authorship and region in the case of international co-authorship

	MNCS	Number of papers	Mean number of authors per paper	Median number of authors per paper
South Africa	0.89	1 771	–	–
No co-authorship	0.85	185	–	–
Domestic co-authorship only	0.76	698	–	–
International co-authorship	1.00	888	–	–
SADC	1.98	15	17	3
Rest of Africa	0.81	77	44	4
South and Central America and the Caribbean	0.98	26	168	8

5 This result needs to be interpreted with caution as the impact score was calculated for a small sample of papers (n=15).

	MNCS	Number of papers	Mean number of authors per paper	Median number of authors per paper
North America	1.24	219	31	5
Europe	1.01	566	16	5
Asia	1.14	189	32	5
Middle-East	1.22	18	183	4
Australia and Oceania	1.02	51	69	5

Note: Only papers within the five selected WoS subject categories have been considered.

Normalised citation scores have also been calculated for the five WoS subject categories (**Table 4.8**). The average visibility of four of the fields is comparable to the world average (citation scores of at least 0.80). Only Petroleum Engineering has an average visibility (MNCS of 0.54) below the world average, but this figure needs to be treated with circumspection as it applies to only 28 papers.

Table 4.8: Mean normalised citation score (MNCS) of SA energy papers, by WoS subject category

Subject categories	MNCS	Papers
Electrochemistry	0.95	309
Energy & Fuels	0.93	619
Nuclear Physics	0.86	561
Nuclear S&T	0.80	475
Petroleum Engineering	0.54	28

Note: Only papers within the five selected WoS subject categories have been considered.

4.3.8 World Shares of Papers in Energy Research

In order to place the contribution of SA in a global context, the country's papers are expressed as a percentage of the world total. This was done for each of the five WoS categories, as well as for the total collection of energy research papers. The results are summarised in **Table 4.9** to **Table 4.14**. In each table the relative contributions of the Top-10 countries are also reported, for both the overall period (2000–2011) as well as for the different time periods.

The most salient trends to emerge from these analyses are:

- In terms of world shares of papers, the USA is the global leader in energy research for most of the sub-fields, with the exception of Electrochemistry and Energy & Fuels. In the latter two subject categories China recently (2008–2011) emerged as the global leader, accounting for just above 21% of all papers produced.
- Across the board there seems to be a general decrease in the world shares of traditional western countries, such as Germany, the United Kingdom (UK) and France. Germany's contribution, for instance, systematically decreased from 9.9% in 2000–2003 to 6.7% in 2008–2013 (**Table 4.9**).
- SA ranks 38th in the world for energy papers produced over the period 2000–2011 (**Table 4.9**). Its "highest" rank is in the field of Energy and Fuels (rank=36) and its "lowest" in Petroleum Engineering (rank=55) (see **Table 4.10** and **Table 4.11**).

In the field of Electrochemistry, SA has systematically improved its rank over the three-year periods (rankings of 53, 46 and 37, respectively (**Table 4.10**). The opposite is true for Nuclear S&T, where the country's rank has consistently declined (**Table 4.13**).

Table 4.9: World shares of energy papers in the five selected WoS subject categories – SA *versus* Top-10 countries, by year period

Total period: 2000–2011		Period 1: 2000–2003		Period 2: 2004–2007		Period 3: 2008–2011	
Country	World share	Country	World share	Country	World share	Country	World share
USA	21.3%	USA	23.9%	USA	21.9%	USA	19.0%
China	11.8%	Japan	12.0%	Japan	10.1%	China	17.5%
Japan	9.7%	Germany	9.9%	China	9.3%	Japan	7.9%
Germany	8.3%	Russia	6.5%	Germany	8.5%	Germany	6.9%
France	5.8%	France	6.0%	France	5.9%	France	5.4%
UK	4.9%	China	5.9%	Italy	5.4%	Korea	4.6%
Italy	4.9%	UK	5.7%	UK	5.0%	Italy	4.6%
Russia	4.9%	Italy	4.9%	Russia	4.7%	UK	4.4%
Korea	3.6%	Canada	3.3%	India	3.5%	India	4.1%
India	3.6%	India	2.8%	Canada	3.5%	Russia	3.9%
SA (Rank=38)	0.4%	SA (Rank=37)	0.4%	SA (Rank=39)	0.4%	SA (Rank=39)	0.5%

Table 4.10: World shares of energy papers in Electrochemistry – SA *versus* Top-10 countries, by year period

Total period: 2000–2011		Period 1: 2000–2003		Period 2: 2004–2007		Period 3: 2008–2011	
Country	World share	Country	World share	Country	World share	Country	World share
USA	18.1%	USA	21.7%	USA	18.3%	China	21.5%
China	15.1%	Japan	15.7%	China	12.8%	USA	16.2%
Japan	11.5%	Germany	7.2%	Japan	12.3%	Japan	8.8%
Korea	7.0%	France	6.2%	Korea	7.0%	Korea	8.0%
Germany	5.7%	China	5.2%	Germany	5.9%	Taiwan	6.3%
France	5.4%	UK	5.1%	France	5.6%	France	4.9%
Taiwan	5.0%	Russia	5.0%	Taiwan	4.8%	Germany	4.8%
UK	3.9%	Korea	5.0%	UK	4.2%	Spain	3.9%
India	3.7%	Italy	3.5%	Italy	4.0%	India	3.8%
Italy	3.7%	India	3.4%	India	3.9%	Canada	3.5%
SA (Rank=44)	0.3%	SA (Rank=53)	0.1%	SA (Rank=46)	0.2%	SA (Rank=37)	0.5%

Table 4.11: World shares of energy papers in Energy and Fuels – SA *versus* Top-10 countries, by year period

Total period: 2000–2011		Period 1: 2000–2003		Period 2: 2004–2007		Period 3: 2008–2011	
Country	World share	Country	World share	Country	World share	Country	World share
USA	19.8%	USA	21.8%	USA	18.8%	China	21.4%
China	15.9%	China	9.2%	China	11.9%	USA	19.5%
Japan	6.3%	Japan	8.7%	Japan	6.4%	Japan	5.1%
UK	4.7%	UK	5.4%	UK	4.8%	UK	4.4%
Germany	4.6%	Germany	5.2%	Germany	4.7%	Canada	4.4%
Canada	4.4%	Canada	4.4%	Canada	4.4%	Germany	4.3%
India	3.5%	France	3.5%	India	3.6%	India	3.9%
France	3.4%	Russia	3.0%	France	3.4%	Korea	3.7%
Korea	3.2%	Korea	2.5%	Korea	2.9%	France	3.4%
Spain	2.9%	India	2.5%	Spain	2.8%	Spain	3.3%
SA (Rank=36)	0.5%	SA (Rank=38)	0.3%	SA (Rank=35)	0.5%	SA (Rank=35)	0.5%

Table 4.12: World shares of energy papers in Petroleum Engineering – SA *versus* Top-10 countries, by year period

Total period: 2000–2011		Period 1: 2000–2003		Period 2: 2004–2007		Period 3: 2008–2011	
Country	World share	Country	World share	Country	World share	Country	World share
USA	23.1%	USA	24.3%	USA	18.8%	USA	23.8%
China	8.0%	Russia	7.2%	China	11.9%	China	16.9%
Canada	7.0%	Canada	6.0%	Canada	6.4%	Canada	9.0%
Russia	5.7%	UK	4.9%	Russia	4.8%	Russia	5.5%
UK	4.6%	France	2.9%	UK	4.7%	UK	4.5%
France	3.4%	Japan	2.6%	Japan	4.4%	Iran	4.2%
Japan	3.1%	Norway	2.1%	France	3.6%	France	3.6%
Norway	2.7%	China	1.9%	Norway	3.4%	Norway	3.0%
Germany	2.1%	Germany	1.8%	Germany	2.9%	Japan	2.5%
Iran	1.9%	Netherlands	1.2%	Australia	2.8%	Germany	2.3%
SA (Rank=55)	0.1%	SA (Rank=43)	0.1%	SA (Rank=63)	0.1%	SA (Rank=58)	0.1%

Table 4.13: World shares of energy papers in Nuclear S&T – SA *versus* Top-10 countries, by year period

Total period: 2000–2011		**Period 1: 2000–2003**		**Period 2: 2004–2007**		**Period 3: 2008–2011**	
Country	World share	Country	World share	Country	World share	Country	World share
USA	22.6%	USA	24.6%	USA	24.7%	USA	18.7%
Japan	14.0%	Japan	15.5%	Japan	14.1%	Japan	12.4%
Germany	11.8%	Germany	13.0%	Germany	11.5%	Germany	11.0%
France	8.0%	Russia	7.8%	Italy	8.2%	France	8.5%
Italy	7.4%	France	7.6%	France	8.0%	China	7.5%
Russia	6.4%	Italy	6.7%	Russia	6.2%	Italy	7.4%
UK	5.6%	UK	6.3%	UK	5.6%	Korea	5.7%
China	4.9%	Switzerland	3.9%	Switzerland	4.2%	Russia	5.3%
Switzerland	3.8%	China	3.2%	China	4.0%	UK	5.0%
Korea	3.8%	India	2.8%	India	3.1%	India	4.8%
SA (Rank=38)	0.4%	SA (Rank=36)	0.4%	SA (Rank=38)	0.4%	SA (Rank=39)	0.4%

Table 4.14: World shares of energy papers in Nuclear Physics – SA *versus* Top-10 countries, by year period

Total period: 2000–2011		**Period 1: 2000–2003**		**Period 2: 2004–2007**		**Period 3: 2008–2011**	
Country	World share	Country	World share	Country	World share	Country	World share
USA	25.0%	USA	27.3%	USA	26.5%	USA	21.1%
Germany	15.2%	Germany	17.1%	Germany	14.9%	China	13.8%
Japan	11.1%	Japan	12.1%	Japan	11.0%	Germany	13.6%
China	10.0%	Russia	10.5%	China	9.4%	Japan	10.3%
Russia	9.3%	Italy	8.5%	Italy	8.7%	Russia	9.1%
Italy	8.5%	France	8.4%	Russia	8.5%	France	8.5%
France	8.5%	China	6.7%	France	8.5%	Italy	8.2%
UK	5.6%	UK	6.1%	UK	5.5%	India	5.2%
India	4.2%	Switzerland	4.1%	Poland	4.0%	UK	5.1%
Poland	3.9%	Poland	3.8%	India	4.0%	Spain	4.2%
SA (Rank=35)	0.7%	SA (Rank=34)	0.7%	SA (Rank=39)	0.5%	SA (Rank=31)	0.9%

The relative country contributions to the production of energy research presented in the tables above, do not include any form of normalisation. A different picture (in terms of relative contributions to global energy research) emerges if differences in the size of the R&D workforce of each country are considered. For each country the total number of papers for 2008–2011 was divided by the number of full-time equivalent (FTE) researchers, and the resulting quotients multiplied by 100 in order to produce the number of papers per 100 FTE researchers. The results are shown in **Table 4.15**. As can be noted, when controlling for size of workforce, SA records higher levels of productivity compared to the traditional "power houses" in energy research (e.g. USA, China, Germany, Japan, the United Kingdom (UK) and France). For instance, SA produced 5.75 papers per 100 of the FTE research workforce compared to only 3.28 and 2.99 in the case of the USA and China. Italy is the "best" performer in energy research when controlling for the size of the research workforce. SA, compared to the "power houses", seems to be particularly productive in the fields of Energy & Fuels and Nuclear Physics (respectively 2.28 and 1.51 papers per 100 FTE researchers).

Table 4.15: Number of energy papers per 100 of FTE researchers, SA *versus* Top-10 countries (2008–2011, by WoS subject category)

Country	All fields	Electro-chemistry	Energy & Fuels	Petroleum Engineering	Nuclear S&T	Nuclear Physics
Italy	9.16	Not Top-10	Not Top-10	Not Top-10	2.75	2.42
South Africa	**5.75**	**1.11**	**2.28**	**0.05**	**0.81**	**1.51**
France	4.59	0.89	1.18	0.12	1.34	1.06
Germany	4.37	0.65	1.11	0.06	1.29	1.26
Korea	3.61	1.35	1.17	Not Top-10	0.83	Not Top-10
UK	3.51	Not Top-10	1.45	0.14	0.75	0.61
USA	3.28	0.60	1.38	0.16	0.60	0.54
China	2.99	0.79	1.50	0.11	0.24	0.35
Japan	2.50	0.60	0.66	0.03	0.73	0.48
Russia	1.80	Not Top-10	Not Top-10	0.10	0.46	0.63
Canada	Not Top-10	1.01	2.36	0.46	Not Top-10	Not Top-10
Iran	Not Top-10	Not Top-10	Not Top-10	No data	Not Top-10	Not Top-10
Norway	Not Top-10	Not Top-10	Not Top-10	0.89	Not Top-10	Not Top-10
Spain	Not Top-10	1.29	2.08	Not Top-10	Not Top-10	0.95
Taiwan	Not Top-10	2.18	Not Top-10	Not Top-10	Not Top-10	Not Top-10

Note: FTE researchers for 2010 were used, taken from OECD StatExtracts (http://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB; accessed on 11 February 2014).
The Top-10 countries are those with the largest world shares in the respective fields.

4.3.9 Publication Practices of Scholars in Energy Research

As indicated above, a total of 1 965 papers met the criteria for inclusion in this study. These papers were published in 174 journals. However, 28 journal titles account for nearly 70% of the papers produced. **Table 4.16** lists these journal titles in descending order according to the number of papers published in them. **Table 4.16** also includes information on three other key variables:

- **WoS Subject Category:** With a few exceptions, (See below) the vast majority of papers appeared in Thomson-Reuters WoS journals. Therefore, the WoS subject category for each journal (where a journal was classified in more than one category, the category in which it recorded the highest rank was selected) is listed.
- **Journal Rank:** The WoS Journal Citation Reports include reference to the position of a journal in relation to all journal titles in a specific subject category. These ranks have included as they allow for more rigorous comparison across subject categories; for example: the journal *Physical Review C* is ranked 3rd out of a total of 21 journals in the subject category of Nuclear Physics.
- **Journal Impact Factor (JIF) (2013):** Where available, the JIF for each journal was included in the table.

Table 4.16: List of journals in which SA energy papers were published (SA journal titles indicated in bold)

Journal	WoS subject category	Journal rank	JIF 2013	No of papers	Row %
Physical Review C	Physics, Nuclear	3/21	3.715	168	8.5%
Journal of Energy in Southern Africa	Energy & Fuels	70/81	0.211	166	8.4%
Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms	Instruments & Instrumentation	28/57	1.266	122	6.2%
South African Journal of Science	Multidisciplinary Sciences	24/56	0.835	75	3.8%
Electrochimica Acta	Electrochemistry	6/26	3.777	66	3.4%
Energy Policy	Environmental Sciences	51/210	2.743	55	2.8%
Fuel	Engineering, Chemical	11/133	3.357	55	2.8%
International Journal of Electrochemical Science	Not a WoS journal (IBSS journal)	Not available	Not available	54	2.7%
Nuclear Instruments & Methods in Physics Research Section A-Accelerators Spectrometers Detectors and Associated Equipment	Instruments & Instrumentation	30/57	1.142	52	2.6%
Applied Radiation and Isotopes	Radiology, Nuclear Medicine & Medical Imaging	88/120	1.179	52	2.6%
Nuclear Physics A	Physics, Nuclear	11/21	1.525	51	2.6%
Energy & Fuels	Engineering, Chemical	16/133	2.853	39	2.0%
Bioresource Technology	Biotechnology & Applied Microbiology	19/160	4.75	38	1.9%
Hyperfine Interactions	Not a WoS journal (IBSS)	Not available	N/A	38	1.9%
Electroanalysis	Chemistry, Analytical	22/75	2.817	36	1.8%
Nuclear Engineering and Design	Nuclear Science & Technology	19/34	0.805	36	1.8%
Journal of Physics G-Nuclear and Particle Physics	Physics, Particles & Fields	5/27	5.326	35	1.8%
Fuel Processing Technology	Engineering, Chemical	17/133	2.816	27	1.4%
Applied Thermal Engineering	Mechanics	16/135	2.127	26	1.3%
Radiation Physics and Chemistry	Chemistry, Physical	95/135	1.375	26	1.3%
Solar Energy Materials and Solar Cells	Materials Science, Multidisciplinary	29/241	4.63	26	1.3%
European Physical Journal A	Physics, Particles & Fields	13/27	2.043	26	1.3%
Radiation Measurements	Nuclear Science & Technology	17/34	0.861	24	1.2%
Journal of Radioanalytical and Nuclear Chemistry	Chemistry, Analytical	48/75	1.467	24	1.2%
Renewable Energy	Energy & Fuels	18/81	2.989	23	1.2%
International Journal of Modern Physics A	Physics, Particles & Fields	19/27	1.127	21	1.1%

The most salient points are as follows:

- The vast majority of papers in this field appeared in international WoS journals. Only two SA journals feature in the Top-28: the *Journal of Energy in Southern Africa* (8.4% of total output) and the *South African Journal of Science* (3.8%). Both these journals recorded rather low impact factors. The fact that the *Journal of Energy in Southern Africa* was only added to the WoS in 2008 could partially explain this, but it is more likely that papers published in these two journals are single or nationally co-authored papers with little international visibility.
- For the remainder, a significant proportion of papers appeared in quite high impact journals and in journals that are ranked reasonably highly in their respective subject categories. In **Table 4.17** all journals with impact factors of two and above are listed. Papers published in these 13 journals constitute nearly one-third (32%) of all papers.

Table 4.17: Journals with impact factors of 2.0 and above

Journal	WoS subject category	Journal rank	JIF 2013	No. of papers	Row %
Journal of Physics G-Nuclear and Particle Physics	Physics, Particles & Fields	5/27	5.326	35	1.8%
Bioresource Technology	Biotechnology & Applied Microbiology	19/160	4.75	38	1.9%
Solar Energy Materials and Solar Cells	Materials Science, Multidisciplinary	29/241	4.63	26	1.3%
Electrochimica Acta	Electrochemistry	6/26	3.777	66	3.4%
Physical Review C	Physics, Nuclear	3/21	3.715	168	8.5%
Fuel	Engineering, Chemical	11/133	3.357	55	2.8%
Renewable Energy	Energy & Fuels	18/81	2.989	23	1.2%
Energy & Fuels	Engineering, Chemical	16/133	2.853	39	2.0%
Electroanalysis	Chemistry, Analytical	22/75	2.817	36	1.8%
Fuel Processing Technology	Engineering, Chemical	17/133	2.816	27	1.4%
Energy Policy	Environmental Sciences	51/210	2.743	55	2.8%
Applied Thermal Engineering	Mechanics	16/135	2.127	26	1.3%
European Physical Journal A	Physics, Particles & Fields	13/27	2.043	26	1.3%

4.4 Concluding Remarks

A bibliometric study was conducted on papers published in the broad field of energy. The dataset produced for the study used two strategies to identify unique papers published between 2000 and 2011. First, five journal subject categories from the WoS were taken as providing sufficient coverage of both nuclear and non-nuclear energy research in SA. These subject categories are: Energy & Fuels, Electrochemistry, Petroleum Engineering, Nuclear Science & Technology, and Nuclear Physics. In addition to the above "core" dataset, which included all SA papers in the five selected subject categories, more relevant papers were identified by means of a follow-up strategy, and added to the "core" dataset. The follow-up strategy consisted of the following: searching for additional WoS papers (i.e. papers not covered by the five WoS subject categories) by extracting all articles with the word "energy" in either the title, journal name, author address or article keywords; searching a database of SA papers for articles with the word "energy" in the title or keywords, and; searching the *Journal of Energy in Southern Africa* for papers that include at least one author with a SA affiliation. The above strategies resulted in a database of 1 965 papers (i.e. 1 771 from the "core" dataset and 194 additional papers).

Finding 1: Trends in publication output: There has been a steady increase in SA's publication output in energy research between 2000 and 2011, with an overall growth of 257% in output over the period. Although this growth occurred from a small base (only 82 papers in 2000), the increase has been relatively steady and consistent, culminating in the production of 293 papers in 2011.

Finding 2: Publication output by subject category: The general trend in overall output masks rather significant differences when the output is disaggregated by subject category. Two fields – Electrochemistry, and Energy & Fuels – recorded the largest and most consistent increases in output (with average annual growth rates of 30.6% and 20.8% respectively). In both cases, output started increasing very steeply over the past five years. The output in the other three categories remained basically unchanged with no or very little growth.

Finding 3: Publication output by institution: The production of scientific papers produced over the past 12 years in SA has been dominated by five institutions: UCT, SU, Wits, iThemba LABS and UP. These five institutions together produced nearly two-thirds (65%) of the total output. Other significant contributions were made by NWU, UWC, RU and CSIR. However, although UCT produced the overall largest proportion of output (18%), its contribution in the most recent period declined slightly to 15%. SU, whose total share over the total period constitutes 13%, managed in the most recent period to equal UCT's share (15%). The relative shares of Wits and iThemba LABS have declined over the total period although they remain significant contributors to the overall production. Conversely, UWC, NWU and CSIR have recorded noticeable increases in their relative contributions to papers in these fields.

Finding 4: Publication output by sector: Three sectors were identified as contributing to scientific papers in energy in SA: the university sector, the science council sector (CSIR, iThemba LABS) and other (e.g. Necsa, Sasol and PBMR). Perhaps not unexpectedly, the university sector dominates output and also increasingly so (their share increased from 83% to 88% in the most recent period).

Finding 5: Trends in country collaboration: An analysis was done to establish which countries contribute most, in terms of co-authorship, to the production of SA energy papers. The results show that whereas Germany initially assumed the first position in 2000–2003 (13%), it has declined relative to the USA in 2004–2007 (13%). Although the USA maintained its lead in 2008–2011, the size of its relative share subsequently declined (from 13% to 8%). China is growing in prominence as a collaborating country for SA energy research. Although China does not feature in the list of the Top-10 co-authoring countries in either 2000–2003 or 2004–2007, it occupies the third position in the list for the most recent period (2008–2011).

Finding 6: Trends in country collaboration disaggregated by subject category: In terms of the individual subject categories, Electrochemistry has a markedly different collaboration profile than those of the other subject categories. It is not dominated by the USA or Germany as main collaborating country, but by Nigeria and China.

Finding 7: Regional contributions to SA's publication output: Three regions dominate as collaborators with SA scholars: Europe (30% of all papers), North America (11%) and Asia (10%). That being said, Europe's contribution has been consistently declining (from 36% in 2000–2003 to 26% in 2008–2011), whereas that of Asia has increased (from 5% in 2000–2003 to 14% in 2008–2011).

Finding 8: Trends in multiple authorship: Multiple authorship is, and has been, the norm in this field, with small percentages of single-authored papers. In fact, the number of single authorship papers declined from 18% in the earliest period to 8% in the most recent period. It is also significant that international co-authorship is the most prevalent and again showing a steady increase to the extent that nearly 50% of all papers in this field over the past three years involved authors from overseas institutions. International co-authorship of papers in the field of Nuclear Physics is the most dominant, with nearly three in every four papers involving foreign authors. In the sub-fields of Electrochemistry and Energy & Fuels, however, national collaborations are more common.

Finding 9: Citation impact of SA energy papers: The overall field-normalised citation score for the SA papers in energy research is 0.89, which means that the average visibility and impact of these papers is comparable to the world average for the field. This is a positive result as it means that these papers receive recognition from other scholars working in the same field commensurate to most papers published in the world in the field of energy research. It is even more interesting, and not surprising, that the MNCS for internationally co-authored papers equals 1.00. Within this subset, those papers which were co-authored with scientists in other SADC countries (1.98), North America (1.24), the Middle-East (1.22) and Asia (1.14) recorded above world average field normalised scores. The results also confirm a generally accepted principle of scientific publishing, *viz*. that papers that are more local (and which involve national co-authorship only) rarely generate high citation impact.

Finding 10: World shares of energy papers: In terms of world shares of papers, the USA is the global leader in energy research for most of the sub-fields, with the exception of Electrochemistry and Energy & Fuels, in which China recently (2008–2011) emerged as the global leader. SA ranks 38th in the world for energy papers produced over the period 2000–2011. Its "best" rank is in the field of Energy and Fuels (rank=36) and its "worst" in Petroleum Engineering (rank=55). In the field of Electrochemistry, SA systematically improved its rank over the three-year periods (rankings of 53, 46 and 37, respectively). The opposite is true for Nuclear S&T, where the country's rank has consistently declined.

Finding 11: SA's contribution to world production normalised by the research work force: A different picture (in terms of relative contributions to global energy research) emerges if one controls for differences in the size of R&D workforce of each country. The results show that SA, when controlling for size of workforce, records higher levels of productivity compared to the traditional "power houses" in energy research (e.g. USA, China, Germany, Japan, the UK and France). For instance, SA produced 5.75 papers per 100 of the FTE research workforce compared to only 3.28 and 2.99 in the case of the USA and China. SA is particularly productive in the fields of Energy & Fuels and Nuclear Physics (respectively 2.28 and 1.51 papers per 100 FTE researchers).

Finding 12: Publication practices: distribution of output by journal source: The 1 965 papers analysed in this study were published in 174 unique journals. However, 28 journal titles account for nearly 70% of the papers produced. The vast majority of papers in this field appeared in international WoS journals. Only two SA journals feature in the top 28: the *Journal of Energy in Southern Africa* (8.4% of total output) and the *SA Journal of Science* (3.8%).

5 Masters and Doctoral Degrees Output

5.1 Introduction

The bibliometric study of the previous chapter is complemented by an analysis of Masters and doctoral degree outputs at South African HEIs. HEIs have different rules regarding the publication of research performed during postgraduate studies; often different faculties, even at the same HEI, have different rules. In assessing the state of energy research in South Africa, the postgraduate degree output offers an additional view of the level of energy-related research at HEIs.

In assessing the Masters and doctoral degrees output at HEIs, the NRF Stardata database (NRF, 2014), which provides information on approximately 150 000 South African current and completed research projects, including theses and dissertations, was used. This database provides information on all fields of science since 1919.

The records of the Union Catalogue of Theses and Dissertations formerly maintained by Potchefstroom University (now the North-West University) and the Navtech (former technikon research) projects are included in the database. The database also includes abstracts and English titles for projects not in English.

5.2 Methodology

The NRF Stardata database contains the following fields: Titles, Keywords, Subjects, Abstracts, Authors, Institutional Names, Institutional Codes, Year of Completion, Degree (Degree type, Masters, Doctoral), Status (Completed or Incomplete). The institutions not submitting output to the NRF database and/or having no output relevant to this study are not included in the figures and tables that follow.

After a number of trial iterations, searches were undertaken using the following keywords for data from 2006–2014:

coal, fossil, oil, gas, ethanol, methanol, petroleum, renewable, bio, biomass, solar, photo, wind, hydro, wave, geothermal, wood, nuclear, pebble, reactor, storage, battery, hydrogen, fuel cell, atmosphere, SO_x, NO_x, sulphur, SO_2, emission, mercury, CO_2, carbon dioxide, mitigate, manage, control, ignition, combustion, measure, load, model, policy, efficiency.

These keywords were filtered/searched in combination with the following, in a logical "AND" combination: (*energy* OR *power* OR *electricity* OR *fuel*) with * indicating "any character".

In order to avoid titles reappearing in searches using these keywords, titles already appearing in previous searches were eliminated in subsequent searches. While duplication of titles could thus be avoided, it is possible that a limited number of titles may not have been categorised in the best category, e.g. a title containing the words "efficiency" and "environment" would only be placed in one of the two categories. Outputs from the categories above were combined into the categories presented in the figures that follow. It should be noted that many titles could be allocated to more than one category, however, no duplications were allowed and titles were allocated to unique categories based on titles alone.

5.3 Results

The search rendered 412 outputs from institutions listed in **Figure 5.1** indicating the percentage of completed Masters and the percentage of completed doctoral degrees in the system. The full record is included in Appendix 4.

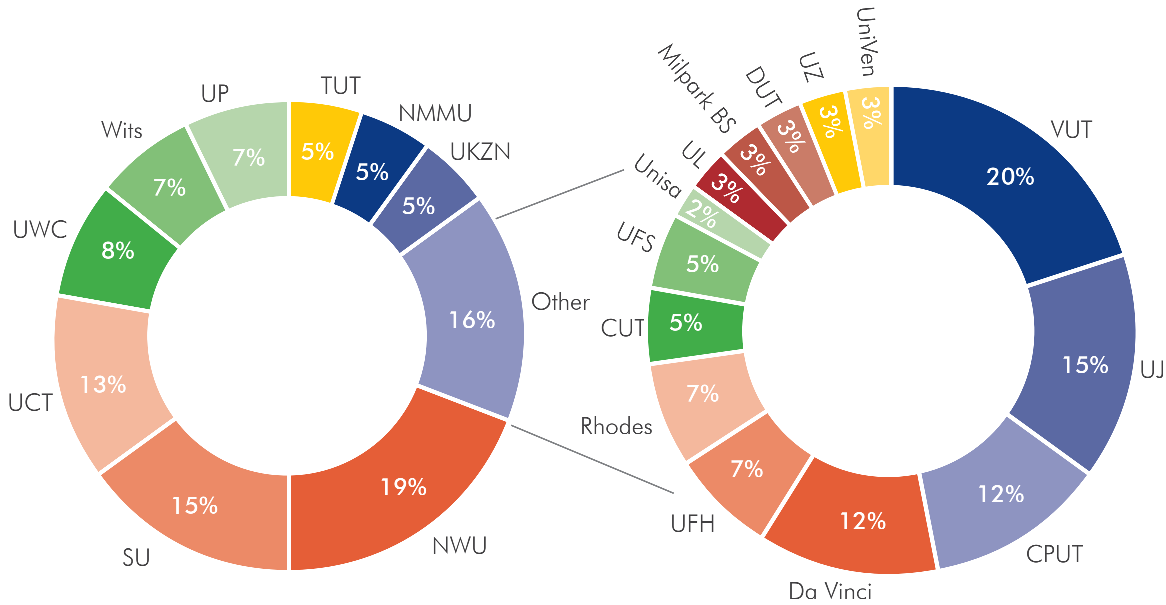


Figure 5.1: Contribution of institutions to completed Masters and doctoral energy-related degrees, 2006–2013 (the pie chart to the right illustrates the contribution of institutions not explicitly listed in the pie chart to the left but instead as "Other")

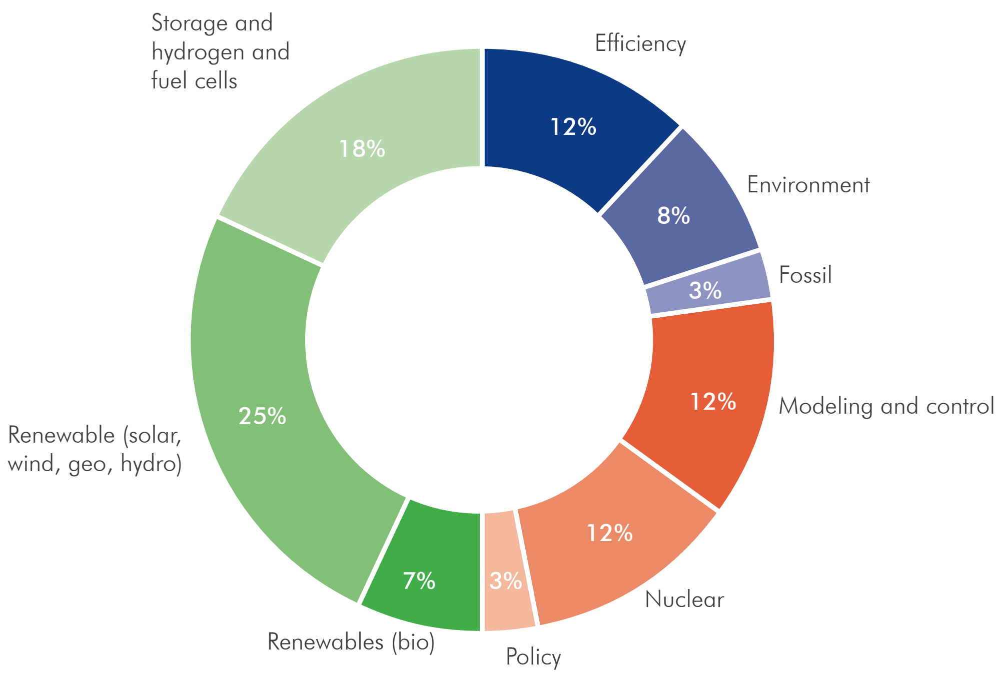


Figure 5.2: Total completed Masters and doctoral energy-related degrees at all HEIs, by energy field, 2006–2013

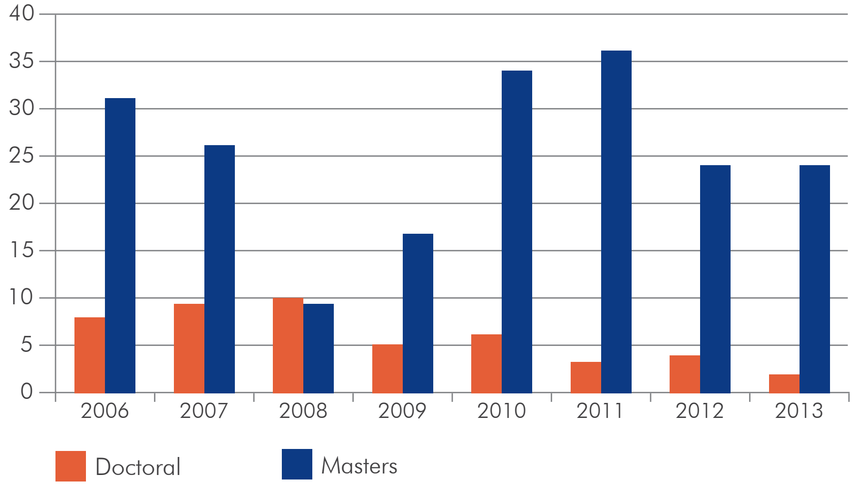


Figure 5.3: Total completed Masters and doctoral energy-related degrees at all HEIs, 2006–2013

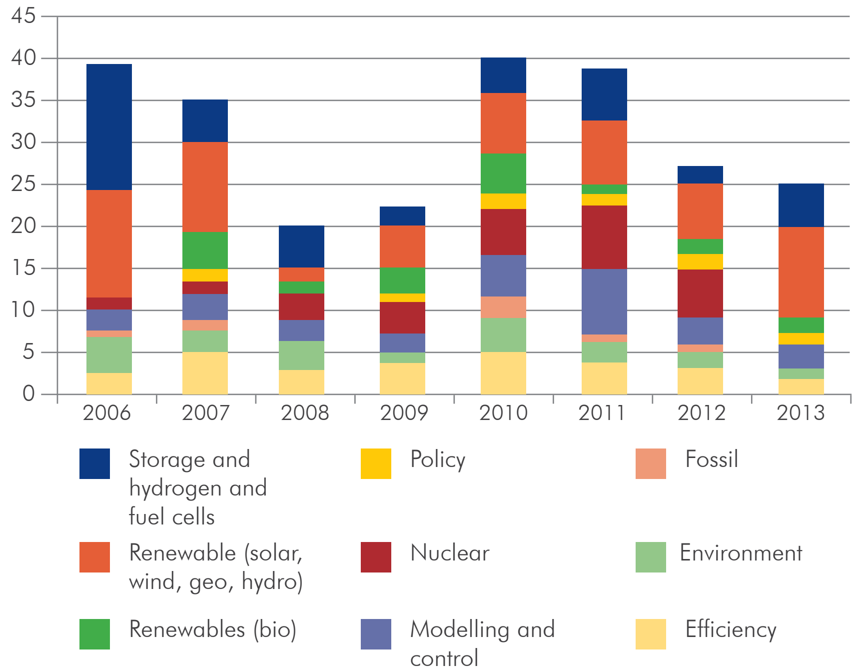


Figure 5.4: Completed Masters and doctoral degrees by energy research category, 2006–2013

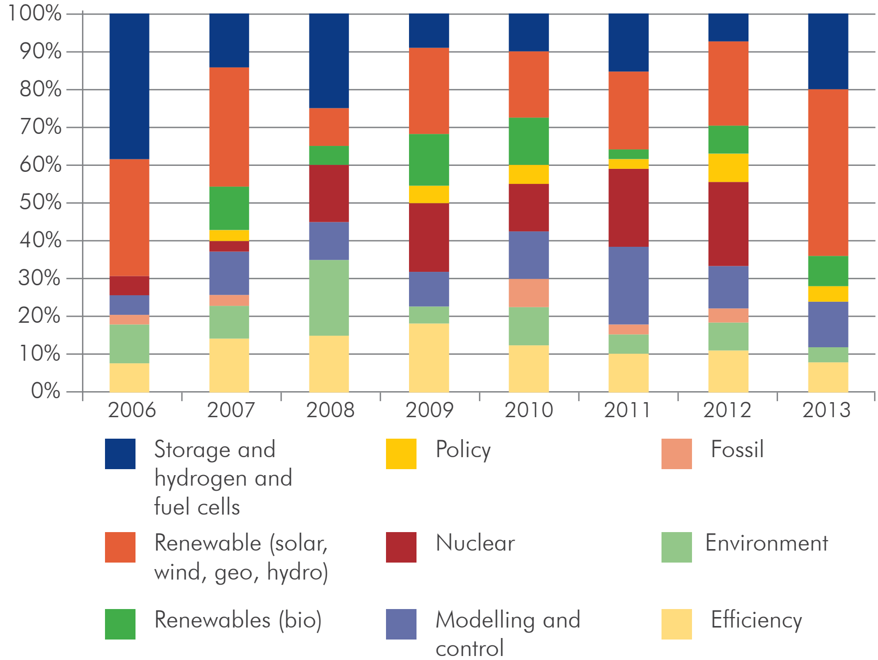


Figure 5.5: Comparative proportions (calculated to 100%) of Masters and doctoral degrees by energy research category, completed and current, 2006–2013

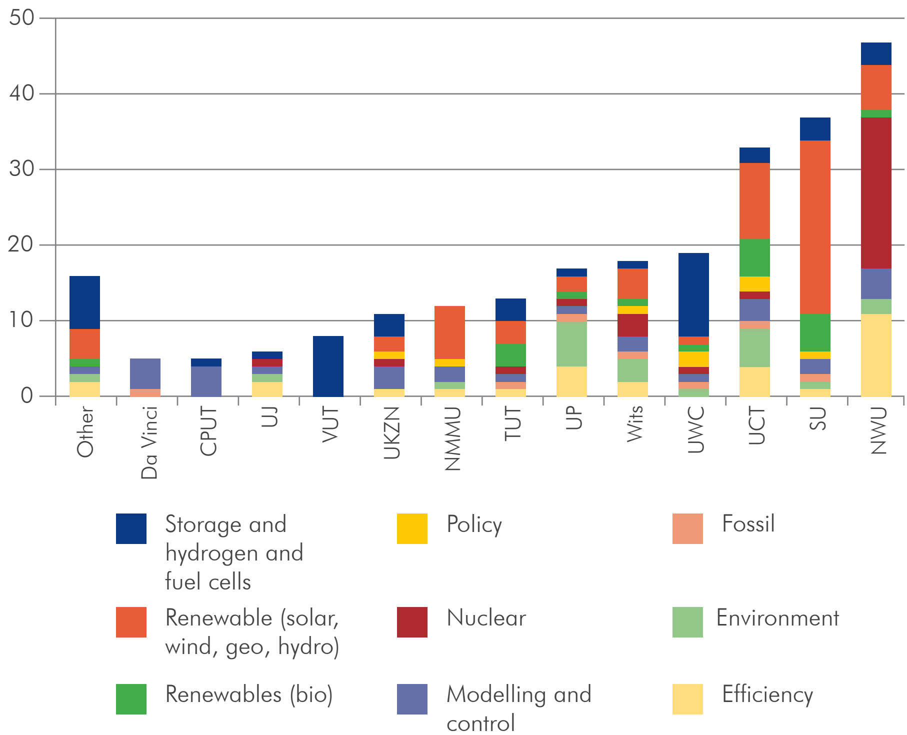


Figure 5.6: Completed Masters and doctoral degrees, by HEI and energy category, 2006–2013

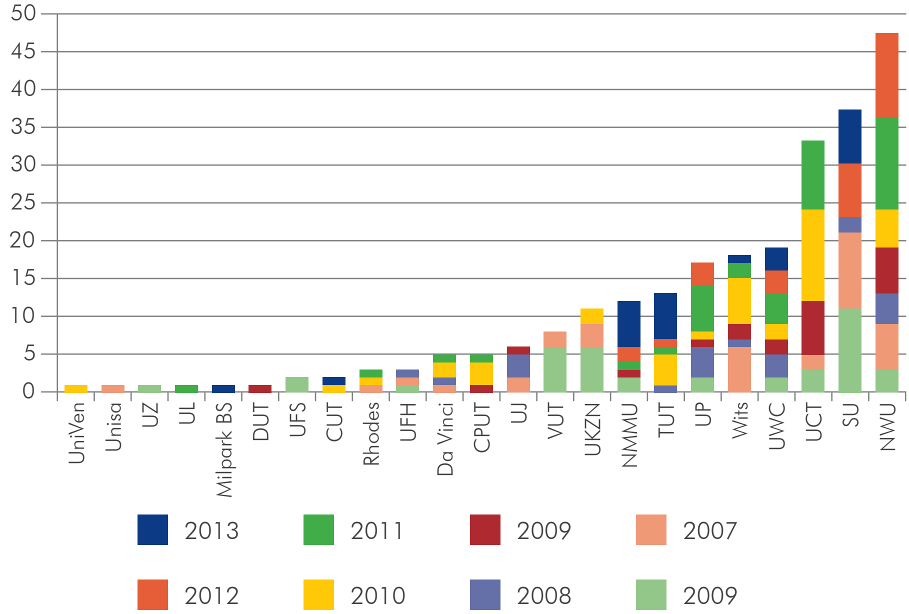


Figure 5.7: Completed Masters and doctoral degrees, by HEI and year

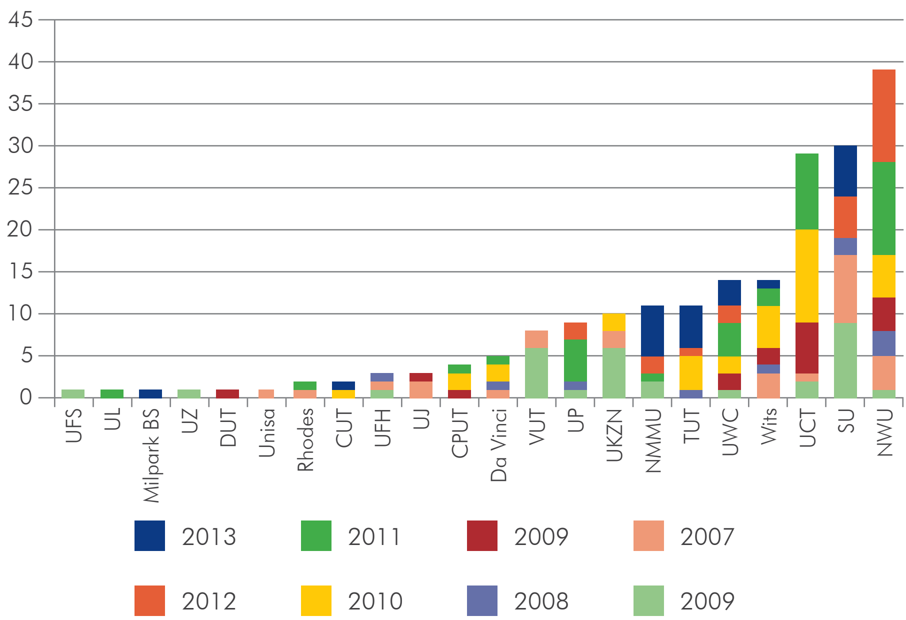


Figure 5.8: Completed Masters degrees, by HEI and year

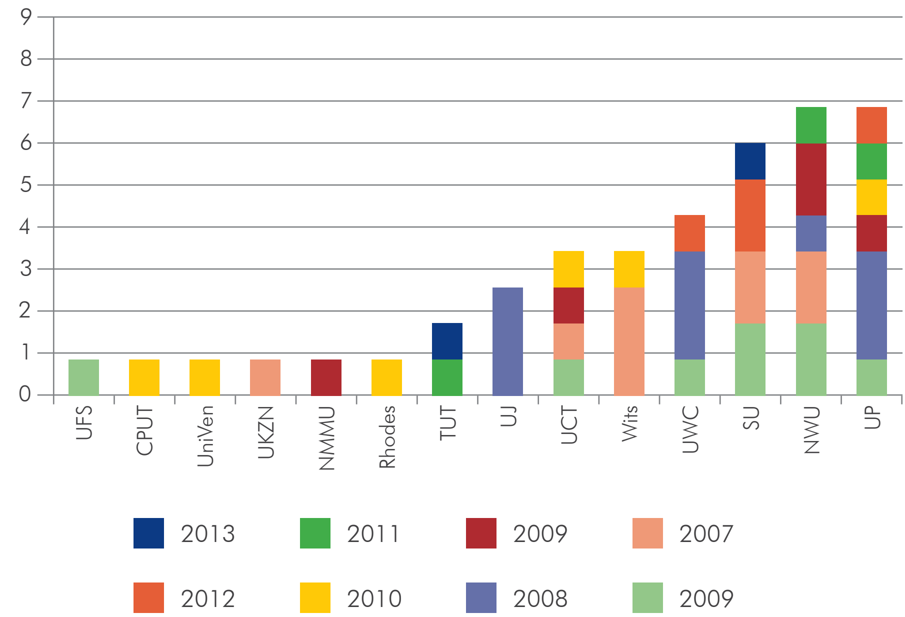


Figure 5.9: Completed doctoral degrees, by HEI and year

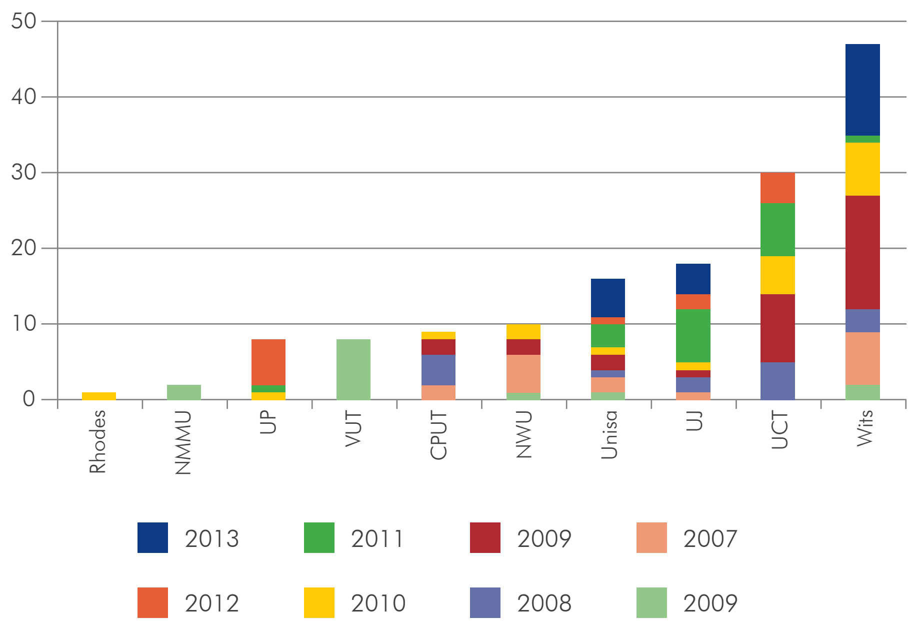


Figure 5.10: Current Masters and doctoral degrees, by HEI and year

5.4 Findings

Seven HEIs (NWU, SU, UCT, UWC Wits, UP and TUT) account for approximately 75% of the completed energy-related Masters and doctoral degrees from 2006–2013 (**Figure 5.1**). 43% of the Masters and doctoral (M&D) output is related directly to renewable energy, nuclear energy and energy from fossil fuels, with 57% of output attributable to storage, hydrogen and fuel cells, efficiency, energy and the environment, policy-related energy studies and modelling and control. The bulk of the research is taking place in renewables (21%) and storage and hydrogen and fuel cells (19%). The fields of nuclear energy, energy efficiency and modelling and control each have a greater than 10% share (**Figure 5.2**).

Postgraduate research, as measured by M&D output (**Figure 5.3**) shows no growth over the period 2006–2013. Research in nuclear energy is decreasing over time, while research in renewable energy is on the increase (**Figure 5.4**). M&D output over the period 2006–2013 was greatest at NWU, SU and UCT, each with over 25 completed degrees (**Figure 5.7**). NWU has a strong focus on nuclear energy, while SU and UCT have a renewable energy focus.

Many institutions have apparently not yet submitted their 2013 outputs to the NRF database. It is also evident that many institutions have not listed any current (i.e. not completed) degrees: **Figure 5.10** indicates that current registrations in energy-related research are confined to ten HEIs. Of the institutions which submitted current enrolments (i.e. not completed degrees), about 75% of M&D degree enrolments are listed by Wits, UCT, UJ and Unisa (**Figure 5.10**). This is due to a combination of good recent enrolments, as well as a number of students moving slower through the system.

The M&D degree output and current registrations are not supporting the future growth in energy development in the country. This is due to a fragmented approach in energy research (with the exception of a number of programmes directly steered by DST, SANEDI, Eskom). Other contributing factors include a relatively low funding base for energy R&D, the lack of a clear roadmap and/or recent disinvestments (e.g. nuclear energy), the shortage of postgraduate students in South Africa and competition from other (often better funded) research programmes.

In summary, **Figure 5.6** and **Figure 5.7** indicate the following institutions to have strengths in:

Renewable energy:	SU, UCT, Wits, NWU
Nuclear energy:	NWU
Fossil-based energy:	Wits, NWU
Energy efficiency:	NWU, Wits, UCT, UP, UJ
Storage and hydrogen and fuel cells:	VUT, UWC, Wits, UCT, NWU, UJ
Energy and the environment:	Wits, UCT, UP
Modelling and control:	CPUT, UCT, Wits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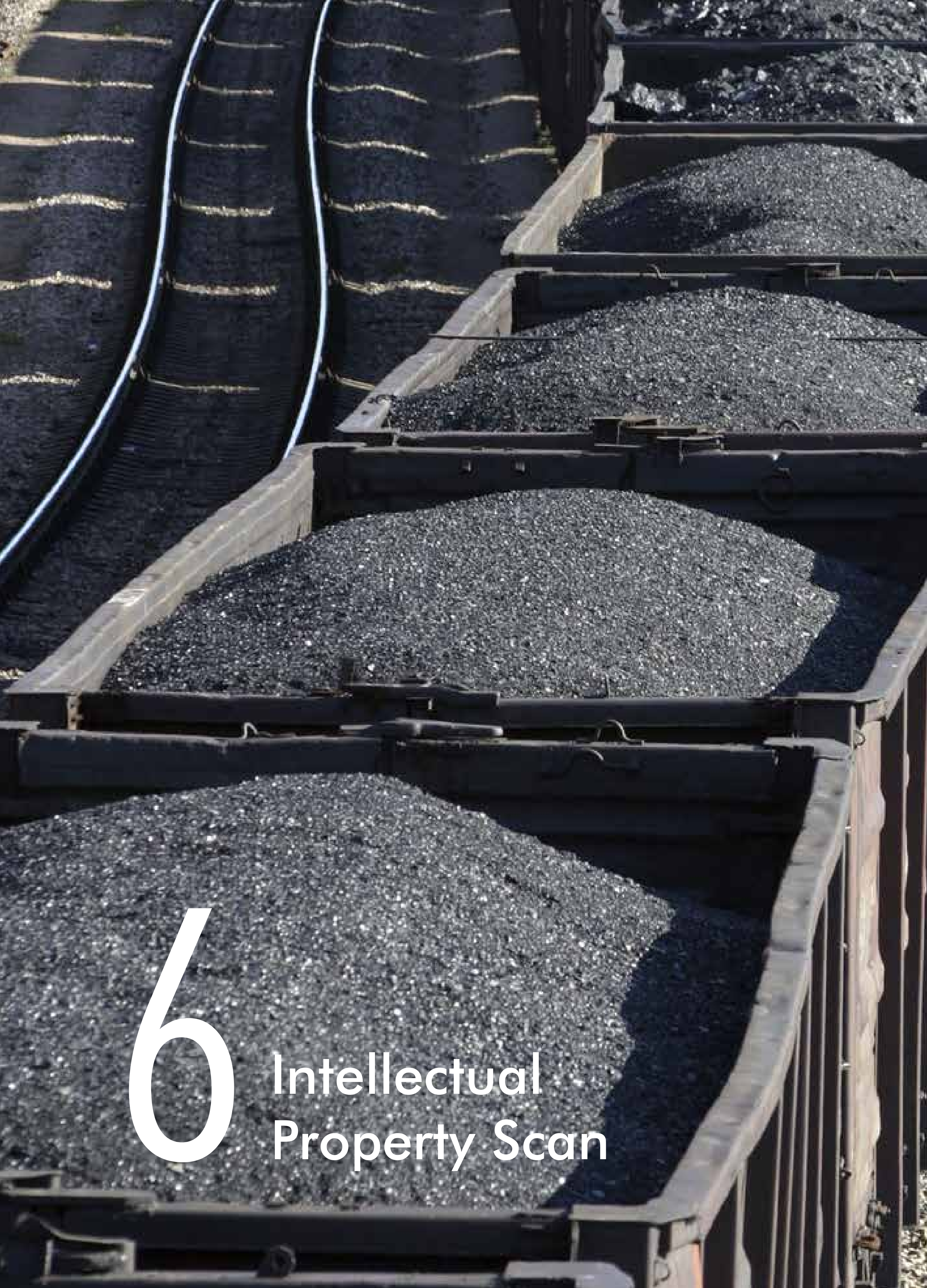

6 Intellectual Property Scan

6.1 Rationale

The role players in the science and innovation system (including HEIs, the public sector and the private sector) have different (albeit often overlapping) objectives. HEIs will emphasise higher degrees, publications, conference papers, books and book chapters as research output. HEIs with established innovation offices and an emphasis on university-industry collaborations may prioritise patenting activities, although the processes of patenting and publishing (if not managed well) may be inherently competing. Technology transfer is generally recognised by successful universities as a core activity. Private companies and individuals may be less interested in publications and more in patenting, given the need to recoup own funds invested in developing innovations.

A study of energy research would therefore be incomplete without an IP scan.

6.2 Scope

An IP scan was undertaken by DM Kisch Patent Attorneys at the request of ASSAf (DM Kisch Patent Attorneys, 2013). The identified fields of energy research were:

- Energy production:
  - renewable energy (including solar, wind, ocean, tide, hydro, geothermal, bio-energy and other forms of renewable energy);
  - nuclear energy;
  - fossil fuel-based energy (including coal, oil and gas).
- Energy storage.
- Energy efficiency.

The intended outcome of the IP scan was to obtain the following information in relation to patents in the above fields, filed both locally and globally by any South African entity (including companies, universities, individuals, etc.): publication number, title, year of application, country of application, name(s) of inventor(s), name(s) of assignee(s) (patent owners), abstract, priority data (including priority number and date) and international patent classification (IPC).

6.3 Search Methodology

Due to the unavailability of a comprehensive electronic South African patent database for purposes of conducting a subject matter search, the search had to be split into two main categories, being a manual South African patent search using IPC classification, and an electronic international subject matter search. For purposes of the South African search, a manual search was conducted through the in-house DM Kisch database for granted patents in the above fields that cite South African inventors and/or assignees. The in-house database was sorted according to IPC classes, and the classes for the respective fields of energy research referred to above could be determined and the search for relevant patents in these classes filed from the year 2000–2010 could be conducted. The South African patent journal has been available electronically since 2010, and the remainder of the search (i.e. 2010 to October 2013) was conducted in the electronic patent journals. The patent journal however only contains bibliographic data in respect of patents, and an electronic subject matter search is still not possible for South African patents.

Upon searching the necessary classes, the abstracts of all South African patents granted from 2000 to October 2013 were identified and perused. (The scope of the study was to provide data only from 2009.) The patents filed by South African inventors and/or assignees that fell within the above fields were extracted from the database and the electronic patent journals, and the information was captured into a Microsoft (MS) Excel spreadsheet.

The international search was conducted via Thomson Innovation, a comprehensive electronic subscription patent database containing patent information from all the major patent jurisdictions. The search was conducted by entering keywords or phrases in relation to the fields defined above, and then limiting the search results to South African inventors and assignees. Due to the electronic nature of the search, and in an effort to provide as much information as possible, the time period in respect of the international search was not limited.

The search results have been captured in electronic format (an MS Excel spreadsheet) to enable filtering, analysis and sorting according to requirements. The search results have also been divided into worksheets according to the respective fields defined above, and the database that was searched (SA or International).

The accuracy of the search is dependent on the accuracy of the records in which the search was conducted. The accuracy of the South African component of the search is further dependent on the accuracy of the classification of the South African patents by the patent office.

The search results were arranged in worksheets in MS Excel, as listed below, where "*SA*" refers to patents filed by South African inventors and/or applicants in South Africa, and "*International*" refers to patents filed by South African inventors and/or applicants in other countries or regions:

- Solar energy – SA and International;
- Geothermal energy – SA and International;
- Hydropower – SA and International;
- Nuclear energy – SA and International;
- Wind energy – SA and International;
- Wave and tidal energy – SA and International;
- Bio-energy – SA and International;

- Fossil fuel-derived energy (including gas, coal and oil) – SA and International;
- Waste to energy – SA and International;
- Hydrogen and fuel cells – SA and International;
- Energy and environment – SA and International;
- Energy storage – International.

During the manual South African search, it was found that the IPC classification in respect of energy storage was not practical or conducive to a search of this nature, due to the vast array of classes in which these patents were classified. A comprehensive international search was conducted to ensure that the majority of international patents that claim priority from South African patents in respect of energy storage were disclosed by the search.

6.4 Analysis

An MS Excel sheet containing comprehensive data in respect of the patents filed by South African inventors and/or applicants in the above fields during the past 13 years (for South African patents), and longer (in respect of international patents) is available.

The patenting process typically makes provision for registration in the country of origin. Should the country of origin be a signatory to the Patent Cooperation Treaty (PCT) (which is the case in South Africa and most other countries), this would give the developer(s) a period of 12 months' protection, during which the patent claims can be affirmed and/or modified. Should wider protection be sought after the 12-month period, a patent application can be filed with the PCT. This application would give the inventor(s) another 18 months for further patent development. The PCT phase is followed by the national (in-country) phase. **Table 6.1** summarises the patent jurisdictions in which South African energy-related patents have been filed from 2000–2014.

Table 6.1: South Africa energy-related patents filed in different jurisdictions

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Great Britain		1													1
Singapore												1			1
Russia								1							1
Germany			3												3
Canada								1	2		1				4
South Korea				3				1	5						9
China						2	2	13	11	6	12	3			49
EU patent convention	7	8	22	3	7	5	5	11	15	9	10	8			110
South Africa	1	4	9	7	6	5	15	16	16	21	22	14	14	1	151
US patent convention		7	11	15	30	7	22	26	12	22	25	33	18	5	233
WO PCT	10	10	36	13	10	8	18	18	21	40	30	27	22	2	265
TOTAL	**18**	**30**	**81**	**41**	**53**	**27**	**62**	**87**	**82**	**98**	**100**	**86**	**54**	**8**	**827**

Note: WO PCT: World Intellectual Property Organisation – Patent Cooperation Treaty

The database supplied by DM Kisch Patent Attorneys (2013) contained more than 1 200 different patent entries. These entries contained patents not relevant to the energy sector in terms of the scope of this study; it contained repetitions and refinements as a result of the patenting development process as well as repetitions by virtue of new registrations during the national phase. The irrelevant patents were removed from the database and the repetitions were highlighted in order to identify patent families (i.e. all patents related to an original patent, which may contain modifications of a mother patent or may have developed from a mother patent).

A new general category, *Energy Control and Conversion*, was also added to house the different patents not linked to any specific energy category. Given the nature of some patents, it was not always possible to map it to a specific energy category. Patents were mapped into categories in terms of the innovation and the patent claims as could be derived from the titles and abstracts.

6.5 Results

The results contained in the database are summarised below in **Table 6.2** and **Table 6.3** as well as **Figure 6.1** and **Figure 6.2**.

6.5.1 Total Number of Patents, Patent Families per Category

The slowing down of all patenting activities from around 2010 may be related to the world economic climate. The DST initiatives around, for example, the hydrogen economy and the bio-economy are expected to render a higher yield in energy-related patents from about 2014 onwards. Developments and patenting activities related to energy are dominated by the categories Renewable Energies (36%), Energy Control & Conversion (24%), Fossil Fuels (17%) and Nuclear (12%).

Table 6.2: Total number of South African and international energy-related patents, per category, 2000–2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Bio-energy			**4**	**2**	**2**	**5**	**1**	**8**	**3**	**7**	**14**		**3**	**1**	**50**
INT			3	2	1	5		8	2	4	12		3	1	41
SA			1		1		1		1	3	2				9
Energy & Environment	**1**	**2**	**1**	**2**	**4**		**1**	**2**	**7**	**3**	**5**	**2**	**3**	**1**	**34**
INT	1	2	1	1	4		1	2	4	1	1		1		19
SA				1					3	2	4	2	2	1	15
Energy Control & Conversion	**9**	**5**	**18**	**11**	**15**	**4**	**10**	**22**	**17**	**19**	**17**	**31**	**15**	**2**	**195**
INT	9	4	18	11	15	4	10	19	17	18	14	28	15	2	184
SA		1						3		1	3	3			11
Energy Efficiency												**3**		**1**	**4**
INT												3		1	4
Energy Storage			**1**		**2**			**4**		**2**		**1**	**1**		**11**

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
INT			*1*		2			4		2		1	1		11
Fossil Fuels	**2**	**10**	**10**		**10**	**7**	**7**	**16**	**13**	**25**	**20**	**11**	**8**	**1**	**140**
INT	1	9	10		9	6	1	10	11	23	15	10	5	1	111
SA	1	1			1	1	6	6	2	2	5	1	3		29
Geothermal				**1**	**2**	**1**		**1**		**1**			**1**		**7**
INT				1	2	1		1		1			1		7
Hydrogen & Fuel Cells	**2**			**3**	**2**		**2**	**4**	**4**	**5**	**15**	**4**	**6**		**47**
INT	2			2	2		2	4	4	5	14	4	5		44
SA				1							1		1		3
Hydropower		**1**					**5**	**10**	**17**	**11**	**6**	**9**			**59**
INT		1					4	7	14	9	6	7			48
SA							1	3	3	2		2			11
Nuclear Energy	**1**	**5**	**40**	**20**	**6**	**5**	**6**	**7**	**3**			**2**	**2**		**97**
INT	1	5	36	15	5	4	1	5	3			2	1		78
SA			4	5	1	1	5	2					1		19
Solar Energy		**3**	**4**	**1**	**8**	**1**	**22**	**11**	**10**	**17**	**18**	**8**	**11**		**114**
INT		3	3	1	7		21	10	7	10	14	5	5		86
SA			1		1	1	1	1	3	7	4	3	6		28
Waste to Energy	**2**	**3**							**1**			**2**	**1**		**9**
INT	2	2										2			6
SA		1							1				1		3
Wave & Tidal Energy	**1**	**1**		**1**		**2**	**4**		**5**	**3**	**3**	**8**		**1**	**29**
INT	1			1			4		4	3		7		1	21
SA		1				2			1		3	1			8
Wind Energy			**3**		**2**	**2**	**4**	**2**	**2**	**5**	**2**	**5**	**3**	**1**	**31**
INT						2	3	1		1	2	3	3	1	16
SA			3		2		1	1	2	4		2			15
TOTAL	**18**	**30**	**81**	**41**	**53**	**27**	**62**	**87**	**82**	**98**	**100**	**86**	**54**	**8**	**827**

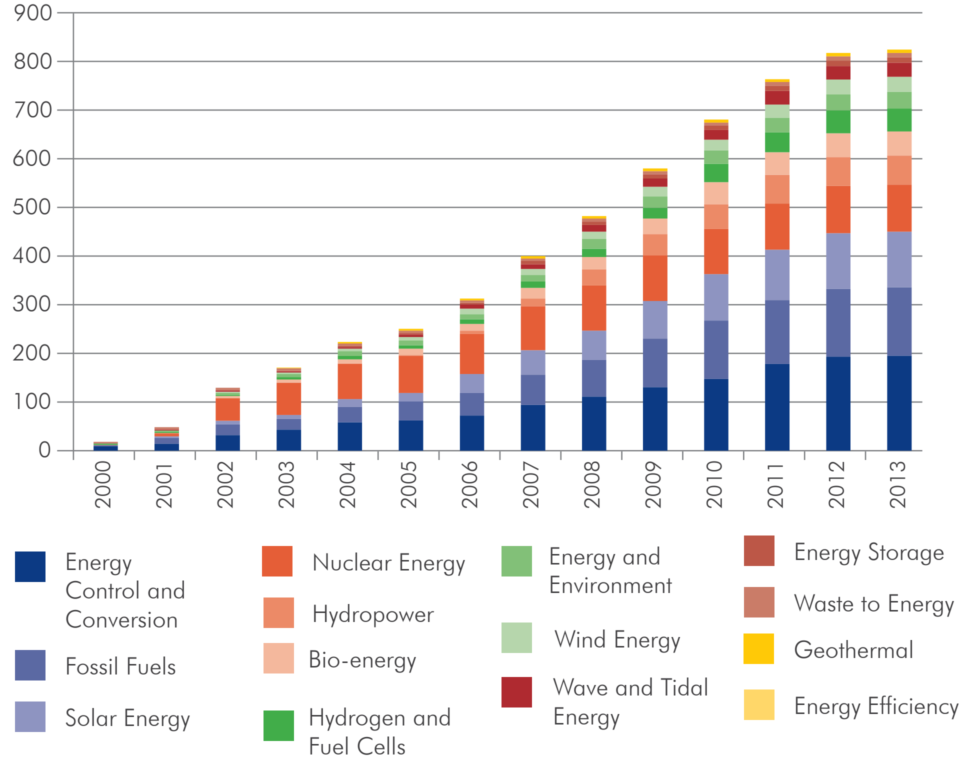

Figure 6.1: Accumulative energy-related patents by category, all jurisdictions, 2000–2013

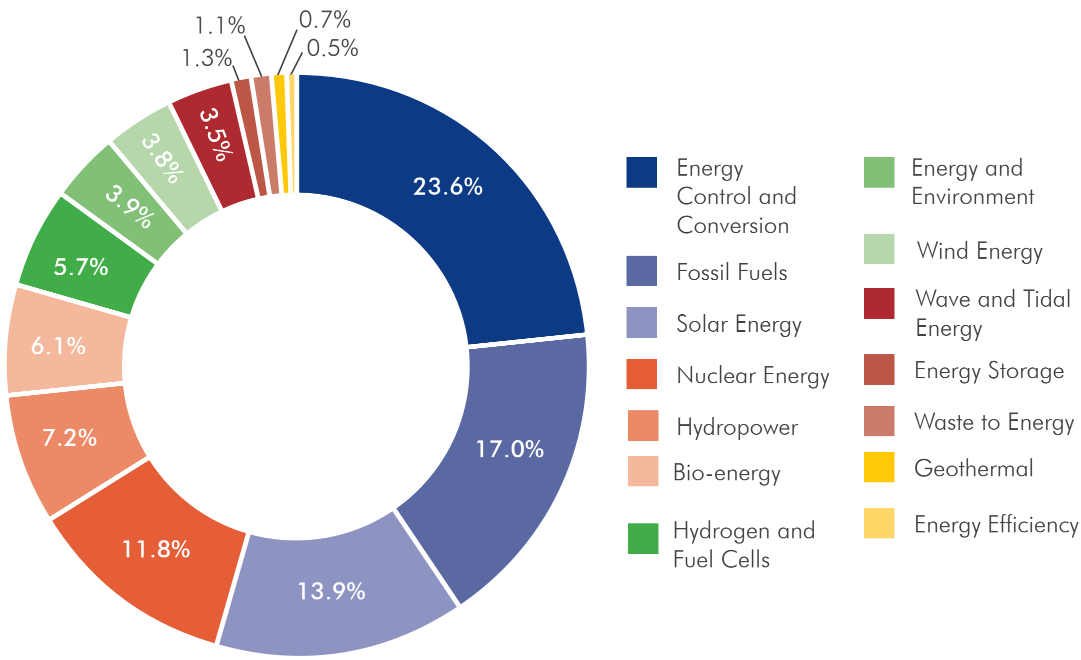

Figure 6.2: Total energy-related patents registered, all jurisdictions, by category, 2000–2013

Table 6.3: Total number of South African and international energy-related patent families, per category, 2000–2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Bio-energy			1	1	1	1	1		2	6	6		2		21
Energy & Environment	1	1		1	2		1	2	6	3	5	2	2	1	27
Energy Control & Conversion	1	1	3	2	2	1	3	5	3	3	10	9	8	1	52
Energy Efficiency												1			1
Energy Storage			1		1			1		1		1			5
Fossil Fuels	2	4	4		3	2	6	6	5	5	13	3	7	1	61
Geothermal					2	1		1					1		5
Hydrogen & Fuel Cells				2	1		1	2	2	2	2	2	3		17
Hydropower		1					2	3	5	3		3			17
Nuclear Energy	1	1	15	10	5	2	3	3					1		41
Solar Energy			3	1	2	1	5	2	6	9	6	7	9		51
Waste to Energy	1	1							1				1		4
Wave & Tidal Energy		1				1			2		3	4		1	12
Wind Energy			3		2	2	2	2	1	5	2	2	3	1	25
TOTAL	**6**	**10**	**30**	**17**	**21**	**11**	**24**	**27**	**33**	**37**	**47**	**34**	**37**	**5**	**339**

6.5.2 Contribution by HEIs, the Public Sector and the Private Sector

The proportional contributions of energy-related patents by HEIs, the private sector and public sector organisations (science councils) are shown in **Table 6.4** and in **Figure 6.3**.

HEIs or science councils (listed as public institutions) typically generate patents in environments or by teams linked to a research programme(s) or institute(s) within the organisation. The outputs in patenting activity are not (yet) directly related to these identified strengths; many of these centres have been established fairly recently and are in a phase of building capacity.

The private sector dominates the patenting field in terms of numbers. Some large companies have an in-depth research base in a specific niche area or sector, a large footprint and huge asset base, such as Sasol or some of the mining groups.

Table 6.4: Proportional contribution to total energy-related patents by HEI and category, public and private institutions, 2000–2014

	HEIs	Private	Public	TOTAL
Energy Control and Conversion	16	178	1	195
Fossil Fuels	25	114	1	140
Solar Energy	20	92	2	114
Nuclear Energy		14	83	97
Hydropower		59		59
Bio-energy	12	38		50
Hydrogen and Fuel Cells	18	27	2	47
Energy and Environment	3	29	2	34
Wind Energy	6	25		31
Wave & Tidal Energy	4	25		29
Energy Storage		11		11
Waste to Energy		6	3	9
Geothermal	1	6		7
Energy Efficiency		4		4
TOTAL	**105**	**628**	**94**	**827**

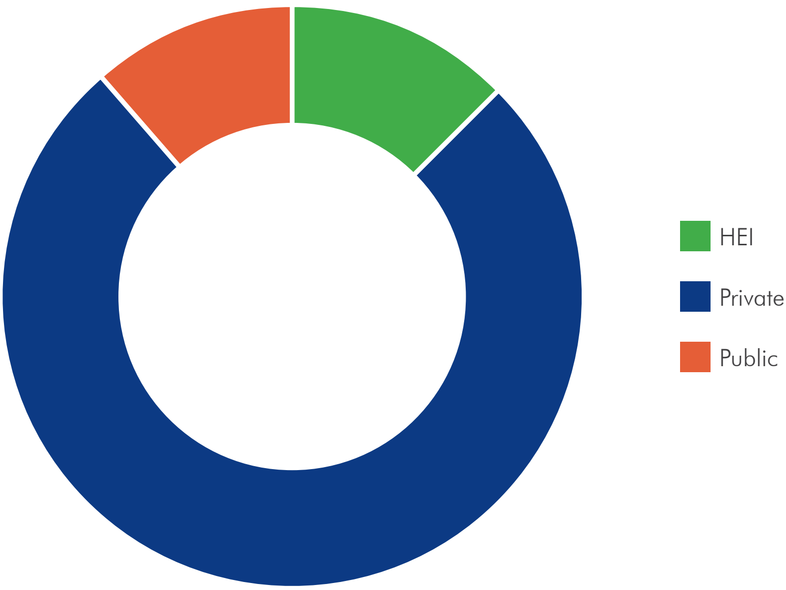

Figure 6.3: Proportional contribution to total energy-related patents by HEI, public and private institutions, 2000–2014

A fair amount of patenting activity (which should be seen as the end product of a longer development cycle) has been emerging from institutions with an in-depth strength in a number of fields, as listed in **Table 6.5**. The energy-related strengths can often be linked to the research and innovation structures listed in Chapter 2, but in many cases the innovations are spin-offs of other programmes.

Table 6.5: Organisations with more than one energy-related patent filed during 2000–2013, all jurisdictions

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Anglo American	2														2
UWC										3					3
Mahala Power												3		1	4
Mioxide Mining											2		2		4
Hydrox Holdings								3	1						4
Alterna Energy				2						1	1				4
Koninklijke Bam Groep							2		2						4
EON Consulting									4						4
Suntracker Dome		3	1												4
TUT										3			1		4
UCT					1						2	2			5
CSIR									2	1		2	1		6
HEIs, outside SA				2	2		1	1	1					1	8
UJ					6		3				1				10
Eskom	2	2	4	1			1						2		12
NWU					1			5	3	2			2		13
SU										3	4	4	2	1	14
BHP Billiton						5				10		9	2		26
Access International Patent								3	9	6	6	3			27
Azoteq		1		1	4	1	1	6	4		4	3	2		27
Wits						1		9	2	3	25	3	3		46
PBMR		3	34	13	3	5	5	7	1			2	2		75
Sasol	1	5	10	1	4	2	6	4	7	16	6	9	2	2	75
TOTAL	**5**	**14**	**49**	**20**	**21**	**14**	**19**	**38**	**36**	**48**	**51**	**40**	**21**	**5**	**381**

Table 6.6: Energy-related patent family by organisations with more than one patent filed during 2000–2013, all jurisdictions

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Mahala Power														1	1
Access International Patent									1						1
Mioxide Mining													1		1
Anglo American	1														1
Koninklijke Bam Groep									1						1

Table 6.6: Energy-related patent family by organisations with more than one patent filed during 2000–2013, all jurisdictions (continued)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
UWC										1					1
Alterna Energy				1											1
Hydrox Holdings								1							1
Suntracker Dome			1												1
UJ							1								1
EON Consulting									2						2
TUT										2			1		3
NWU					1			1	1						3
Azoteq							1	1				1			3
UCT					1						2	1			4
BHP Billiton						1				1		1	1		4
CSIR									2	1			1		4
HEIs, outside RSA					1		1	1	1						4
SU											2	1	2	1	6
Eskom	2		4	1			1						1		9
Wits						1			2	1	11	2	2		19
PBMR		1	9	5	2	2	3	3					1		26
Sasol	1	1	2		3	1	5	4	2	2	2	1	2	1	27
TOTAL	**4**	**2**	**16**	**7**	**8**	**5**	**12**	**11**	**12**	**8**	**17**	**7**	**12**	**3**	**124**

6.6 Concluding Remarks

The general findings, as related to institutions with more than one energy-related patent family, are as follows:

Sasol: A wide range of petro-chemical patent families related to the Fischer-Tropsch suite of technologies have been developed by Sasol.

PBMR: Prior to its closure, PBMR embarked upon a patenting drive to protect its future business in different jurisdictions. Given the state of the programme, the scattered remaining scientists and engineers across various disciplines and countries, and the patent protection window and the time envisaged to develop the first commercial type PBMRs, these patents probably have no commercial value.

Wits: The Wits patent portfolio indicates strengths in bio-energy (bio-reactors, bio-ethanol, algae), synthesis gas production, polymer electrolyte membranes and solar energy.

Eskom: Nuclear energy (related to participation in the PBMR), solar energy (Heliostat field)

SU: Renewable energy (wave/tidal, solar, bio-fuels, wind)

CSIR: Bio-energy, energy control and conversion, solar energy

BHP Billiton: Energy control and conversion, energy efficiency

UCT: Bio-energy, fossil fuels

Azoteq:	Patents in switching and controlling
NWU:	Wind, hydrogen production, ignition
TUT:	Solar energy
EON Consult:	Energy efficiency, demand side management
UJ:	Solar power (PVs)
Suntracker:	Solar energy

The low patenting output, as is evident from the relatively low number of patent families reported, can be attributed to a low awareness of the value of patenting (a trend which has been turned around through a number of interventions by DST), a lack of basic research relevant to energy, as well as the perceived cost associated with patenting. With a number of exceptions, many energy projects are demonstrations of developed technology or are applied research.

It is assumed that as more CoEs and CoCs are established, as is proposed in Chapter 7, a concentration of research activities would lead to more patenting. The proposed coordination mechanisms would also have a positive bearing on establishing a drive for in-depth research development, as well as IP development.

7 Conclusion

7.1 Findings

The current South African indigenous energy resource base is dominated by coal. About 77% of South Africa's primary energy needs are provided by coal (DoE, 2014). This is unlikely to change significantly in the next two decades owing to the current lack of suitable alternatives to coal as an energy source in the quantities needed. Many of the deposits can be exploited at extremely favourable costs. Cheap coal has hitherto been a strategic differentiator for the energy-intensive South African economy. As South Africa embraces the knowledge-based economy as the development thrust for the future and while beneficiation of raw materials is identified as a national priority, the South African economy is bound to remain energy intensive for the foreseeable future. Transport is almost entirely fossil fuel-based with about one third of transport fuel being produced by Sasol from coal, through the Fischer-Tropsch process. Moreover, 92% of coal consumed on the African continent is produced in South Africa, which is the 7th largest hard coal producer in the world (in 2009) (IEA, 2012). South Africa remains a major emitter of CO_2 and is the highest in Africa. In terms of electricity generation, 93.2% is generated from coal (compared with 40% worldwide), 4.2% by nuclear power and 1.3% by hydropower (NERSA, 2006).

The transformation of the energy sector is central to decoupling economic growth from negative ecological impacts and excessive resource use and shifting to a low carbon growth path. Green technologies in the energy sector therefore have a critical role to play (Brent *et al.*, 2009; 2012). To transform the South African energy sector, green technologies, including energy efficient technologies, renewable energy technologies, nuclear energy, as well as technologies aimed at producing clean coal, should be promoted.

In addition, government is planning for a carbon tax of approximately R120 per ton of CO_2 in the 2015 budget. National Treasury released the Carbon Tax Paper for public comment in May 2013 (National Treasury, 2013c).

The national priorities for energy include the need for energy security, protecting the environment and access to affordable, safe, clean and reliable energy. This is to be achieved, *inter alia* by a number of major R&D thrusts: clean coal technologies, the use of nuclear energy, embracing renewable energy technologies and by hydrogen as a clean technology (DST, 2008).

The NDP calls for environmental sustainability and resilience and states that South Africa's energy sector will be driven on a path to lower carbon and energy intensity by rising energy prices, an economy-wide carbon tax with sector exemptions, coupled with direct action plans, such as the implementation of the IRP, scaled taxes on the sale of high-emission vehicles, equipment and building standards and targeted energy efficiency programmes (NPC, 2012).

The IRP 2013 proposes an alternative to a fixed capacity plan (as espoused in the IRP 2010), as a more flexible approach, necessitated by uncertainty regarding the future energy demand, the potential for shale gas, the extent of other gas developments in the region, the global agenda to combat climate change and the resulting mitigation requirements on South Africa, as well as the uncertainty in the cost of nuclear capacity and future fuel costs (specifically coal and gas), including fuel availability (DoE, 2013).

7.1.1 Gaps and Research Opportunities by Field

In general, energy and energy-related research could play an extremely important role in the development and establishment of the knowledge-based economy in South Africa. CO_2 reduction and job creation is a policy requirement relevant to all energy fields. Energy and energy-related research has immense job creation potential, while the outputs of this research has direct and immediate advantages for the economy through actual CO_2 reduction, local economic development and assisting South Africa in honouring its international climate-related commitments.

Energy and energy-related R&D programmes are not optimally aligned with national priorities and are not sufficiently funded to make a significant impact in all fields required.

Clean Coal Technologies

Given the fact that coal is expected to dominate South African energy supply for the foreseeable future, investments in coal R&D are insufficient:

- clean coal technologies (including CO_2 mitigation and efficiency in coal production) are not sufficiently funded, and
- CCS research programmes are limited.

Based on the continued use of coal in parallel with the stringent and imminent cap on GHG emissions, methods to ensure the cleaner use of coal in South Africa are of immediate and paramount importance (**Table 7.1**).

The majority of the coal R&D is being performed by Eskom, Sasol, Wits and NWU.

Table 7.1: National priorities, gaps and research opportunities related to clean coal technologies

Reference	Requirement	Gaps/Research opportunities
(NPC, 2012)	Cleaner coal technologies will be promoted through R&D investments and technology-transfer agreements in, among others, the use of ultra-supercritical coal-power plants, fluidised-bed combustion, underground coal gasification, integrated gasification combined cycle and carbon capture and storage.	Respondents recommended investment of time and money in various research fields related to: fluidised-bed combustion; UCG; fuel characterisation; performance and testing; emission reduction; future fossil fuel conversion technologies; coal quality and processing; real-time coal analysis; characterisation of untapped coal reserves. Eskom suggested from an industry perspective: the development of a national UCG research strategy for the country, optimised combined electricity/chemical production, better process control and analysis in power generation processes. CCS: Based on the Storage Atlas produced by/for SANEDI, research and development opportunities exist for a pilot project, utilising oxy-fuel and post-combustion carbon capture technologies and/or carbon capture and reuse technologies or any other appropriate technology. Significant research in CCS makes sense in a country with abundant cheap coal as the primary energy source.
(DST, 2008)	80% of new energy capacity is to be supplied by clean coal technologies and nuclear power by 2018.	Given the timeframes involved in erecting new plants/capacity, it seems unlikely that these goals will be met.
(DST, 2008)	70% of energy to come from coal (of which 30% would be based on clean coal technologies), by 2018.	The required research base and the HCD needed to support this goal has yet to be developed.
(DST, 2008)	Expanded the knowledge base for building … coal plants parts; source more than 50% of all new capacity locally.	Insufficient R&D currently supports the need to expand the knowledge base for building coal plant (parts).
(DoE, 2013)	Plant life extension programmes with concomitant environmental compliance modifications, compared to new coal-fired generation which is more efficient and with lower emission rates, or non-emitting alternatives under more aggressive climate mitigation objectives.	Eskom is driving the majority of research and development in this regard, *inter alia* through its EPPEI programme and other developments managed by Eskom.

Gas

Very little/insufficient attention is given to research into shale gas, which has the potential to provide a lower carbon medium-term energy future for South Africa. Research is needed to support possible future exploitation of the resource, to support techno-economic evaluations of exploitation pathways, to determine environmental and other risks, and risk abatement strategies, and to determine beneficiation strategies (**Table 7.2**).

Table 7.2: National priorities, gaps and research opportunities related to gas

<table>
<tr><th>Reference</th><th>Requirement</th><th>Gaps/Research opportunities</th></tr>
<tr><td>(DoE, 2013)</td><td>Pursuing regional and domestic gas options and stepping up shale exploration.</td><td rowspan="2">Eskom reported experience with the use of open cycle gas turbines. Sasol reported research on natural gas conversion to liquids (i.e. GTL), focusing on Fischer-Tropsch-related technology, as well as product work-up.
R&D opportunities include work on: (shale) gas resource assessment; coalbed methane and methane hydrate; gas storage and gas transport; national gas infrastructure: planning, development, financing, implementation; environmental challenges related to shale gas exploration.</td></tr>
<tr><td>(NPC, 2012)</td><td>The extent of economically recoverable coalbed seam and shale gas reserves will be understood. Subject to acceptable environmental controls, these gas resources, supplemented by liquefied natural gas imports, will begin to supply a growing share of power production. This could avoid the need for further base-load nuclear generation.</td></tr>
</table>

Renewable Energy

Research in renewable energy is growing, albeit at a pace lower than the rate needed to meet national targets.

A lack of human capital and research funding is exacerbated by the fact that until recently, the penetration of renewable energy in South Africa has been limited and also mainly restricted to niche markets such as off-grid, rural applications. Recently, a number of promising renewable energy projects have been launched or are in the planning stage.

The fact that there seems to be insufficient coordination between the major role players, DST, DoE, Eskom, SANEDI and others has contributed to the fragmentation of effort and funding in this sphere. There is a need for suitable renewable energy research and test laboratories, including national facilities in areas with significant wind and solar resources. A concerted centralised national effort is required to coordinate biomass-related bio-energy R&D and technology diffusion. The many initiatives need a clear cohesion of research effort; a bio-economy hub to coordinate research efforts across the value chain could greatly benefit the industry, as well as create a central source of funding for biofuels and bio-chemicals research (**Table 7.3**).

Table 7.3: National priorities, gaps and research opportunities related to renewable energy

Reference	Requirement	Gaps/Research opportunities
(DoE, 2013)	Continuation of the current renewable bid programme with additional annual rounds of 1 000 MW PV capacity; 1 000 MW wind capacity and 200 MW CSP capacity, with the potential for hydro at competitive rates.	Research opportunities include: • Development and optimisation of CSP, solar fuel, solar PV technologies and applications; • Development and optimisation of wind, wave and small hydro technologies and applications; • A transition from laboratory-scale studies to pilot-scale demonstration initiatives aimed at commercialising products and processes; • Feedstock qualification and techno-economic and sustainability studies; • Biomass and fossil fuels synergies; • Large-scale biodiesel production from algae; • Developing biogas digester computer prediction models; • Efficient and cost-effective municipal solid waste to energy in plasma gasifiers; • Electricity generation coupled to waste water treatment using membrane-less microbial fuel cells; • The application of genomics and bioinformatics for the molecular genetic characterisation of organisms used as bio-agents for the production of biofuels; • Resource quantification for all forms of renewable energy; • Techno-economic analyses of renewable energy pathways and strategies to accelerate the uptake of renewable energy; • Smart grid solutions linked to distributed small-scale renewable energy solutions; • Energy storage solutions suitable for small and large-scale renewable energy applications.
(NPC, 2012)	Supply at least 20 000 MW of energy from renewable sources by 2030.	
(DST, 2008)	10% of energy used coming from renewable sources (2018).	

Nuclear Energy

Human capital development, as well as R&D in nuclear energy is diminishing, *inter alia*, due to the closure of the PBMR, delays in the decision to procure light water reactor technology and public perceptions regarding nuclear energy safety. As a consequence, some of the milestones of the Energy Grand Challenge (for nuclear energy) (DST, 2008) will not be achieved by 2018 and the country is losing critical skills (**Table 7.4**).

Table 7.4: National priorities, gaps and research opportunities related to nuclear energy

<table>
<tr><th>Reference</th><th>Requirement</th><th>Gaps/Research Opportunities</th></tr>
<tr><td>(DST, 2008)</td><td>Expand the knowledge base for building nuclear reactors and coal plants parts; source more than 50% of all new capacity locally (by 2018).</td><td rowspan="7">South Africa has lost a significant part of its capability in nuclear R&D, compared to its capability which had been built up until about 1990. This capability was temporarily resurrected from 1996 until 2010 when the PBMR project was abandoned. It seems unlikely that the goals relating to (research in) nuclear energy, as stated in the DST 10-Year Innovation Plan and the IRP 2010 will be achieved.

The DST 10-Year Innovation Plan and the approved IRP 2010 plans are aligned, but these documents are not aligned with the NDP 2030 and the IRP 2013 (proposed).

R&D opportunities include:
• Techno-economic evaluations and financing mechanisms for nuclear energy.
• Nuclear safety, environmental costs and benefits.
• Localisation and employment opportunities.
• Uranium enrichment and fuel fabrication.

The implications of delaying the nuclear decision in terms of the country's capability to support (any part of) the nuclear cycle, has to be evaluated and compared with alternative energy supply options.</td></tr>
<tr><td>(DST, 2008)</td><td>Expand the energy supply infrastructure, with 80% of new capacity coming from … and nuclear plants (by 2018).</td></tr>
<tr><td>(DST, 2008)</td><td>Successfully integrate uranium enrichment into the fuel cycle and feeding into the commercial reactors (by 2018).</td></tr>
<tr><td>(DST, 2008)</td><td>10% of energy used coming from renewable sources, 20% from nuclear and 70% from coal (30% would be based on clean coal technologies), by 2018.</td></tr>
<tr><td>(DoE, 2013)</td><td>A possible delay in the nuclear decision until after 2025 or even 2035, by exploring alternative options, such as regional hydro and further exploration of the shale gas potential.</td></tr>
<tr><td>(NPC, 2012)</td><td>While the decision has been taken in principle, further and more in-depth investigations are needed into the implications of greater nuclear energy use, including the potential costs, financing mechanisms, institutional arrangements, safety, environmental costs and benefits, localisation and employment opportunities, and the possibilities of uranium enrichment and fuel fabrication. The National Nuclear Energy Executive Coordinating Committee will make a stop-go decision after actual costs and financing options are revealed.</td></tr>
<tr><td>(NPC, 2012)</td><td>The extent of economically recoverable coalbed seam and shale gas reserves will be understood. This could avoid the need for further base-load nuclear generation.</td></tr>
</table>

Energy Efficiency

The adoption of energy efficiency initiatives is limited. Energy efficiency is a low-hanging fruit in terms of energy saving and GHG mitigation. The promising energy efficiency initiatives employed to date are based on a sound policy framework, as well as significant budget provided for implementation. The insufficient power reserves in the country and other limiting factors regarding coal added a sense of urgency to the implementation of these initiatives. Eskom led the main EE programme (the EEDSM Programme), financed mainly through electricity tariffs. The programme introduces tax allowances for EE in Sections 12I and 12L of the Income Tax Act of 1962 as incentives for energy conservation. Registered measurement and verification bodies (accredited by the South African National Accreditation System (SANAS)), compile savings reports.

In spite of these energy efficiency measures, there is still a lack of commitment and adoption of energy efficient measures. This issue can be resolved by improving awareness and understanding of energy efficiency and implementing effective incentives for the participation of the energy saving drive. More stringent legislation needs to be implemented to drive energy efficiency together with incentive schemes. Financing needs to be adequately available and incentives need to be implemented (**Table 7.5**).

Table 7.5: National priorities, gaps and research opportunities related to energy efficiency

Reference	Requirement	Gaps/Research opportunities
(DST, 2008)	A well-articulated energy efficiency programme and per capita energy demand reduced by 30%.	Research opportunities include: R&D on technological advances for green buildings; ultra-efficient devices; high-efficiency lighting; customer behaviour research; energy efficiency and demand management enablers.
SANEDI mandate	Energy efficiency: (i) undertake energy efficiency measures as directed by the Minister; (ii) increase energy efficiency throughout the economy; (iii) increase the gross domestic product per unit of energy consumed; (iv) optimise the utilisation of finite energy resources.	

Hydrogen and Transport

The HySA initiative managed by DST has completed its establishment phase. Several programmes are underway and are aiming at achieving set milestones (**Table 7.6**).

Table 7.6: National priorities, gaps and research opportunities related to hydrogen and transport

Reference	Requirement	Gaps/Research opportunities
(DST, 2008)	A 25% share of the global hydrogen infrastructure and fuel cell market with novel PGM catalysts (by 2018).	Achieving the milestone is, however, not solely an R&D challenge; the creation of economic development zones to attract manufacturers of fuel cells, electrolysers and other products using PGMs is pivotal to success.
(DST, 2008)	Have demonstrated (by 2018), at pilot scale, the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source.	If sufficient funding is provided/sourced, the production of hydrogen by electro-chemical water splitting (electrolysis) at pilot scale is achievable by 2018, but the production of hydrogen by thermo-chemical water splitting at pilot scale could only be achieved by a later date. Both cases only apply to using a solar source.
(NPC, 2012)	Encourage greater use of hybrid or electric vehicles and public transport. A shift to electric vehicles will increase electricity demand and will have implications for network design, smart metering and tariff structures that encourage off-peak use. Greater use of public transport will also be encouraged, as outlined in the transport section of the plan.	Following the development of the Joule electric vehicle, South Africa demonstrated its ability to develop a competitive electric vehicle. This project has been stopped. It is unclear as to whether the project may be taken into its industrialisation phases, in which case the associated roll out of the project will require further R&D.

Table 7.6: National priorities, gaps and research opportunities related to hydrogen and transport (continued)

Reference	Requirement	Gaps/Research opportunities
(NPC, 2012)	In the transport sector, the emphasis will be on increasing energy efficiency and the resilience of transport networks, drawing on progress in establishing renewable energy resources.	Techno-economic studies are needed to support future work on planning and implementing transport networks.

Energy Economy and Policy

Methodologies and programmes need to be developed to encourage adoption of and participation in energy efficiency strategies. Life-cycle costs of new technologies need to be evaluated to determine the long-term economic benefit of the investment. Energy efficiency efforts and commitments are centred on the medium term and on managing loads until new capacities come online. There is a need for a shift towards energy efficiency as a tool for long-term planning (**Table 7.7**).

Table 7.7: National priorities, gaps and research opportunities related to energy economy and policy

Reference	Requirement	Gaps/Research opportunities
(NPC, 2012)	Rising energy prices, an economy-wide carbon tax with sector exemptions, coupled with direct action (such as the implementation of the IRP in the electricity sector; scaled taxes on the sale of high-emission vehicles, equipment and building standards; and targeted energy efficiency programmes) will drive South Africa's energy sector on a path to lower carbon and energy intensity.	Efficiency improvements in industrial processes and households are generally relatively inexpensive and offer vast energy savings with a concomitant positive impact on the environment. Research opportunities include: • Modelling of power rationing and energy conservation and the associated impact on the economy for future decision-making. • The nature, implementation and impact of an economy-wide carbon tax. • Smart grid options: The development and management of small-scale distributed energy options. • Techno-economic and socio-political implications of regional collaboration in energy supply.
(DoE, 2013)	Developing small-scale distributed generation options.	
(NPC, 2012)	The NDP recognises a changing global economy and the need for increased regional cooperation through exploiting complementary national endowments for mutually beneficial cooperation, such as investing in and helping to exploit the wide range of opportunities for low-carbon energy from hydroelectric and other clean energy sources in southern Africa.	
(DoE, 2013)	Exploring regional hydro projects in Mozambique and Zambia and other regional coal options.	

Energy Storage

Challenges relating to energy storage include technological challenges, market and regulatory issues, the development of a systemic or holistic approach to storage, bridging technical, regulatory, market and political aspects.

The economic and business case varies from case to case, depending on where the storage is needed: generation, transmission, distribution or customer level. The benefits for users/operators are also closely linked to the question of storage location (**Table 7.8**).

Table 7.8: National priorities, gaps and research opportunities related to energy efficiency

Reference	Requirement	Gaps/Research opportunities
(DoE, 2010)	A 25% share of the global hydrogen infrastructure and fuel cell market with novel PGM catalysts (by 2018).	Research opportunities include: • The development of energy storage and efficiency and policy frameworks. • Large centralised and small decentralised storage: integration of storage concepts in the national grid and in renewable energy systems. • Ownership and compensation schemes of the future energy storage systems.

7.1.2 Insufficient Human Capital Development

Human capital development (HCD) in energy and energy-related research is insufficient: Despite energy being identified as one of the Research and Innovation Grand Challenges in the DST 10-Year Innovation Plan and the prominence given to energy in the NDP and other policy documents, the energy and energy-related Masters and doctoral degree output is not growing, *inter alia*, due to:

a) competition from other well-funded research programmes;

b) insufficient funding for energy and energy-related R&D;

c) closure of the PBMR project;

d) the absence of or insufficient investment in R&D instruments, such as research chairs, CoEs and/or CoCs.

7.1.3 Focused Energy Programmes

- SANEDI is supporting a significant and well-coordinated suite of energy projects, aligned with national priorities. However, the budgetary allocations made to SANEDI since 2011 to date, as well as planned until 2015/16 (See Section 2.6.3) are inadequate to execute the SANEDI mandate in terms of the National Energy Act. The optimal resourcing and placement of SANEDI in the national research agenda is of paramount importance.

  SANEDI currently supports the following energy programmes:

  › Bio-energy

    i. Microalgae to Energy

    ii. Macroalgae to Energy

    iii. Waste to Energy

    iv. Biogas Production

  › Renewable Energy

    v. Alternative Transportation

    vi. Ocean Energy

    vii. Photovoltaic Systems (including concentrating PV and other PV technologies)

    viii. Solar Thermal Energy (at low and high temperature and pressure)

    ix. Wind Energy

    x. Resource Mapping

- › Fossil-based Energy
  - xi. Carbon Capture and Storage
  - xii. Shale Gas
  - xiii. Clean Coal Technologies
  - xiv. Resource Mapping
- › Energy Storage
  - xv. Chemical Storage (Solar fuel cells)
  - xvi. Thermal Energy Storage (Solar heat storage)
  - xvii. Battery Technologies
- › Energy Efficiency
  - xviii. Energy Efficient Buildings
  - xix. Energy Efficiency Monitoring and Evaluation
  - xx. Energy Efficiency and Demand Side Management (EEDSM) Hub

- Eskom is supporting a significant and well-coordinated number of energy projects aimed at supporting core business, with significant budget. Current programmes, aligned with national priorities, include:
  - › Fossil Fuel
    - Coal Quality Analysis, Characterisation, Combustion and Handling
    - Underground Coal Gasification
    - System Dynamics Modelling into Diesel and Water Use and Customer Satisfaction Drivers
    - Load Research and Forecasting
    - Atmospheric Dispersion Modelling
  - › The National Energy Efficiency and Demand Side Management Programme
  - › Renewable Energy
    - Renewables Integration onto the National Grid
    - CSP for Energy Production, Desalination, Storage and Industrial Uses
    - Solar Augmentation
    - Municipal Solid Waste Feasibility Study
    - Eskom PV Plants Performance Evaluation
    - Smart Grid Situational Awareness
  - › Other:
    - Air Quality Monitoring and Biomonitoring

- Necsa is currently focusing R&D efforts in the field of nuclear medicine and not nuclear energy. It was, however, emphasised that Necsa (as a result of the deliberate "two-pronged approach" to their research programme) claims to have all the relevant skills and resources available to facilitate the design and implementation of nuclear energy reactors if/when government decides to move ahead with plans to increase the energy capacity in the country through nuclear energy. In general, priorities include:

- “New build” of nuclear power reactors to cope with energy demand in South Africa, reactor safety and responsible disposal of nuclear waste.
- All R&D aspects related to the envisaged localisation programme which is planned to form part of the procurement plan.

- The HYSA hydrogen programme has been established by DST, with significant funding (See Section 2.6.2). The programme supports the knowledge-based economy and is intended to lead to significant local PGM beneficiation. Three CoCs, to function according to the hub-and-spoke model, have been established for R&D and commercialisation in Catalysis at UCT (with MINTEK as co-host), in Systems at UWC and in Infrastructure (including production, reticulation, storage) at NWU (with CSIR as co-host). The centres are in varying stages of development/establishment and outputs in terms of HCD and research and have not yet reached full potential.
- Apart from the above, the following energy or energy-related strengths, aligned with national priorities, have been identified (in specified fields), based on the Masters and doctoral degrees conferred, patents developed, as well as publication output:
  - Sasol (fossil fuels and Fischer-Tropsch)
  - NWU (nuclear energy, coal technology, renewable energy, energy efficiency)
  - SU (renewable energy)
  - UCT (energy policy, renewable energy)
  - UWC (hydrogen and fuel cells)
  - Wits (renewable energy, fossil fuels)
  - UP (energy efficiency)
  - NMMU (renewable energy)

7.2 Recommendations

7.2.1 Coordination: State Departments

It is proposed that government departments with an energy budget (e.g. DST, DoE, the dti and the DPE) establish a formal coordination mechanism, in accordance with the recommendations of the NDP, with a mandate to steer, plan and coordinate energy and energy-related R&D funded with public money, eliminating gaps and overlaps, taking into account national imperatives and priorities.

An alternative approach which is likely to strengthen collaboration among state departments is to consider a centralised Science and Technology vote for all R&D activities across state departments. If such an approach is adopted, science councils could report to DST and could take on contract work for other departments (as is currently the case with CSIR).

7.2.2 Coordination: Public Sector, HEIs and the Private Sector

It is proposed that a national Energy Research and Development Desk, as a committee under the auspices of the National Advisory Council on Innovation (NACI) or ASSAf, be established:

- to report to the appropriate coordination mechanism/department (See paragraph above);
- with representation from relevant state department agencies (including DST, NRF, TIA, SANEDI, IDC), science councils and state enterprises (CSIR, Necsa, Eskom), HEIs with an active energy research portfolio and private sector companies (or communities of practice) with a substantial energy research portfolio and/or energy intensive operations;

- with a mandate to advise state departments and the private sector on energy and energy-related research strategy, budgets and expenditure, to develop energy and energy-related road maps and development and implementation strategies, taking into account international imperatives and national priorities;
- to coordinate energy and energy-related research and to stimulate collaboration and capacity development;
- to coordinate and share funds, eliminating unnecessary duplication and closing gaps;
- to advise on the establishment of triple-helix innovation structures;
- to be led by an experienced, strong and respected individual.

7.2.3 Energy and Energy-related Research Budget and Funding of Collaboration

South Africa's R&D intensity is estimated at 0.76% for 2011/12. This is below the world average of 1.77%, the European Union's average of 1.94% and the Organisation for Economic Co-operation and Development (OECD) average of 2.37%. Among Brazil, Russia, India, China, South Africa (the BRICS countries), R&D intensity was above 1% in Brazil, China and the Russian Federation, and below 1% in South Africa and India (2007 data). (HSRC, 2014).

The NDP 2030 emphasises innovation, improved productivity, job creation, more intensive pursuit of a knowledge-based economy and better exploitation of comparative and competitive advantages in an integrated continent. It is imperative that the R&D intensity in South Africa be substantially increased if this goal is to be achieved. It is recommended that at least 1.5% of the fiscal appropriation be earmarked for R&D support, and that a higher proportion of this be earmarked for energy than is currently the case. Intelligent use of "matching funding" instruments will encourage greater private sector co-investment too.

In addition, it is recommended that a more substantial portion of the national R&D vote be allocated to energy and energy-related research in line with national priorities. Research programmes should be driven upon agreement by the relevant state departments and based on advice by the proposed national Energy Research and Development Advisory Desk. The energy and energy-related programmes should be aligned with national priorities, managed in a rigorous project management environment (similar to the USA DoE and the EU R&D programmes), with collaboration between organisations and capacity building being a prioritised funding requirement.

7.2.4 Human Capital and Capacity Development

The cost of educating and training the numbers of skilled engineers and technologists that will be required to assist in the energy transformation in the near future is a daunting aspect, given the already low skills capacity in the country at present and indeed, globally. Urgent HCD interventions are required if the country is to meet its low carbon goals.

Human capital development for energy areas aligned with the national energy agenda needs to be prioritised. It is proposed that more research chairs, CoCs and CoEs be established and funded in line with established funding patterns. CoCs and CoEs have the additional advantage that inter-institutional collaboration is required.

Hub-and-spoke-based CoEs and/or CoCs should be established (with suitable research and test laboratories), in a number of energy fields, based on the national imperatives for energy R&D, international trends and existing strengths at South African institutions (as identified by the activity map in **Table 3.1** and reported activities in Chapter 3 and the Questionnaire database), as well as the bibliometric analysis (Chapter 4), the analyses in IP strengths (Chapter 5) and the postgraduate output (Chapter 6). Candidates include: Clean Coal Technologies, CCS, Combustion and UG Gasification, Shale Gas, Solar Energy (PV), Solar Energy (CSP), Solar Energy (Solar Fuels), Wind Energy, Bio-energy, Nuclear Energy, Energy Efficiency, Energy Storage, Energy Policy and Planning. It is expected that the CoCs/CoEs would be relatively affordable when compared to the investment required to establish a local industrial capacity to emerge from market trends and the development of appropriate strengths.

Similarly, existing research chairs (DST, Eskom) and new to-be-established research chairs could be positioned in or close to these to-be-established CoCs/CoEs to enhance the research agenda and to avoid unnecessary duplication or gaps.

It is believed that through these funding structures the lack of human resource development and infrastructure, the apparent lack of collaboration between institutions, as well as common challenges identified throughout the survey, would be resolved and could lay the foundation for energy research and development (and much-needed industrialisation and commercialisation) to support the energy-intensive South African economy.

7.2.5 General Energy Field-related Recommendations

In general, energy and energy-related research could play an extremely important role in the development and establishment of the knowledge-based economy in South Africa. CO_2 reduction and job creation is a policy requirement relevant to all energy fields. Energy and energy-related research has immense job creation potential, while the outputs of this research have direct and immediate advantages for the economy through actual CO_2 reduction, local economic development and assisting South Africa in honouring its international climate-related commitments.

Coal

Based upon the continued use of coal in parallel with the stringent and imminent cap on GHG emissions, methods to ensure the cleaner use of coal in South Africa are of immediate and paramount importance. Investment in clean coal technologies and CCS should be increased to provide a solid scientific foundation for a dominating (and expected to be dominating in the foreseeable future) energy source. (More detail is provided in **Table 7.1** and Section 3.6).

Gas

Significant R&D is needed in shale gas, which has the potential to provide a lower carbon medium-term energy future for South Africa. Research is needed to support possible future exploitation of the resource, to support techno-economic evaluations of exploitation pathways, to determine environmental and other risks, risk abatement strategies and to determine beneficiation strategies. (More detail is provided in **Table 7.2** and Section 3.6).

Renewable Energy

Significant investment of the R&D effort in renewable energy is needed to meet national targets. The penetration of renewable energy in South Africa should be increased through appropriate mechanisms. A stronger coordination is needed to circumvent fragmentation of R&D efforts. Small-scale, off-grid renewable energy systems, especially for rural areas should also be included as a priority area as this is one sector where South Africa needs to make significant progress in the next few years. (More detail is provided in **Table 7.3** and Sections 3.3 and 3.4).

Nuclear Energy

The implications of delaying the nuclear decision in terms of the country's capability to support (any part of) the nuclear cycle, has to be evaluated and compared with alternative energy supply options. (More detail is provided in **Table 7.4** and Section 3.5).

Energy Efficiency

In spite of energy efficiency measures such as the EEDSM programme, the commitment to and adoption of energy efficient measures should be increased, *inter alia* by improving awareness and understanding of energy efficiency and implementing effective incentives for the participation of the energy saving drive. More stringent legislation needs to be implemented to drive energy efficiency together with incentive schemes. Financing needs to be adequately available and incentives need to be optimised. (More detail is provided in **Table 7.5** and Section 3.7).

Energy Economy and Policy

Comprehensive techno-economic feasibility studies are needed to inform the national energy R&D agenda, as well as the planning and legislative environment needed for effective implementation on a path to lower carbon and energy intensity. The studies should include development of road maps for all relevant energy categories, as well as its linkage to energy storage, targeted energy efficiency programmes, transportation networks, distributed energy networks and regional collaboration for energy supply. (More detail is provided in **Table 7.6**, **Table 7.7** and **Table 7.8**).

7.2.6 Regular Updates of the State of Energy Research

A status report that is dependent on survey responses is hampered by incomplete or the absence of responses from the research community. Given the time available for the study, it was not possible to gather more complete information. It is evident that this report provides merely a starting point and there is a need for a regular update against a standard reporting "dashboard". It is recommended that such a regular reporting system be introduced for this critical sector.

References

Brent, A.C., Hietkamp, S., Wise, R.M. and O'Kennedy, K., 2009, Estimating the carbon emissions balance for South Africa, *South African Journal of Economic and Management Sciences*, 12 (3), 263–279.

CREST, 2014, Bibliometric profile of the state of energy research, Centre for Research on Science and Technology (CREST), Stellenbosch.

CRSES, 2013a, Roadmap for solar energy R&D, Centre for Renewable and Sustainable Energy Studies (CRSES) Stellenbosch, http://www.crses.sun.ac.za/technologies-solar.php. Accessed 29 August 2013.

CRSES, 2013b, GIS study of wind power resource potential in South Africa, Centre for Renewable and Sustainable Energy Studies (CRSES), Stellenbosch.

DEAT, 2011, National Climate Change Response White Paper, https://www.environment.gov.za/sites/default/files/legislations/national_climatechange_response_whitepaper.pdf. Accessed 29 August 2013.

De La Rue Du Can, S., Letschert, V., Leventis, G., Covary, T. and Xia X., 2013, *Energy efficiency country study: Republic of South Africa*, Lawrence Berkeley National Laboratory, LBNL Report 6365E, http://ies.lbl.gov/sites/all/files/south_africa_country_study_lbnl_report_final.pdf. Accessed 23 April 2014.

Demirbas, A., 2008, Biofuels sources, biofuel policy, biofuel economy and global biofuel projections, *Energy Conversion and Management*, 49, 2106–2116.

DME, 2003, White Paper on Renewable Energy, Notice 513 of 2004, Department of Minerals and Energy (DME), www.gov.za/documents/download.php?f=68765. Accessed 5 June 2014.

DME, 2007a, Biofuels Industrial Strategy of the Republic of South Africa, Department of Minerals and Energy (DME), http://www.energy.gov.za/files/esources/renewables/biofuels_indus_strat.pdf(2).pdf. Accessed 5 June 2014.

DME, 2007b, Nuclear Energy Policy and Strategy for the Republic of South Africa, Draft for public comment, Department of Minerals and Energy (DME), www.gov.za/documents/download.php?f=72522. Accessed 5 June 2014.

DME, 2008, Nuclear Energy Policy for the Republic of South Africa, Department of Minerals and Energy (DME), http://www.energy.gov.za/files/policies/policy_nuclear_energy_2008.pdf. Accessed 5 June 2014.

DM Kisch Patent Attorneys, 2013, Intellectual property scan, The state of energy research in South Arfrica, DM Kisch Patent Attorneys, Johannesburg.

DoE, 2008, National Energy Act, No. 34, 2008, Department of Energy (DoE), Pretoria.

DoE, 2010, Integrated Resource Plan 2010–2030, October 2010, Department of Energy (DoE), Pretoria.

DoE, 2011, Strategic Plan 2011/12–2015/16, Department of Energy (DoE), Pretoria.

DoE, 2013, Integrated Resource Plan 2010–2030 Update Report, Department of Energy (DoE), Pretoria.

DoE, 2014, Coal resources: overview, http://www.energy.gov.za/files/coal_frame.html. Accessed 29 May 2014.

DST, 2008, Innovation towards a knowledge-based economy, Ten-Year Plan for South Africa (2008–2018), Department of Science and Technology (DST), Pretoria.

DVC Forum, 2011, DVC (Research) Forum input to the Ministerial Review Committee on the science, technology and innovation (STI) landscape, Department of Science and Technology, Pretoria.

Econometrix, 2012, *Karroo shale gas report: Special report on economic considerations surrounding shale gas resources in the southern Karoo of South Africa*, Econometrix Pty Ltd, January 2012.

Edkins, M., Marquard, A. and Winckler, H., 2010, *South Africa's renewable energy policy roadmaps. Report for UNEP research project, enhancing information for renewable energy technology deployment in Brazil, China and South Africa*, 41 pp.

ERC, 2007, *Long-term mitigation scenarios: Technical appendix, Report by Energy Research Centre (ERC)*, report submitted to Department of Environment Affairs and Tourism, Pretoria, October 2007.

Eskom, 2012, *Eskom integrated report*, http://www.pads.eezeepage.co.za/i/69717/9. Accessed 5 June 2014.

Etzkowitz, H. A., 2000, The dynamics of innovation: from national systems and ''Mode 2'' to a triple helix of university–industry–government relations, *Research Policy*, 29, 109–123.

Holm, D., 2009, Renewables in Africa, *Renewable Energy Focus*, 10, 64–65.

HSRC, 2013, *National survey of research and experimental development 2010/2011*, Human Sciences Research Council (HSRC), Pretoria.

HSRC, 2014, *National survey of research and experimental development 2011/2012*, Human Sciences Research Council (HSRC), Pretoria.

IEA, 2012, *World energy outlook 2012*, International Energy Agency (IEA), Paris.

IEA, 2013, *World energy outlook 2013,* International Energy Agency (IEA), Paris.

Lynd, L.R., Von Blottnitz, H., Tait, B., De Boer, J., Pretorius, I.S., Rumbold, K. and Van Zyl, W.H., 2003, Plant biomass conversion to fuels and commodity chemicals in South Africa: A third chapter? *South African Journal of Science*, 99, 499–507.

National Treasury, 2013a, Estimates of national expenditure, Vote 34: Science and Technology, National Treasury, Pretoria, http://www.treasury.gov.za/documents/national%20budget/2013/enebooklets/Vote%20 34%20Science%20and%20Technology.pdf. Accessed 10 June 2014.

National Treasury, 2013b, Estimates of national expenditure, Vote 29: Energy, National Treasury, Pretoria, http://www.treasury.gov.za/documents/national%20budget/2013/enebooklets/Vote%2029%20Energy.pdf. Accessed 10 June 2014.

National Treasury, 2013c, Carbon tax policy paper: Reducing greenhouse gas emissions and facilitating the transition to a green economy, National Treasury, Pretoria, http://www.treasury.gov.za/public%20comments/ Carbon%20Tax%20Policy%20Paper%202013.pdf. Accessed 11 June 2014.

NERSA, 2006, *Statistics 2006 – Electricity supply statistics for South Africa,* South Africa, National Energy Regulator of South Africa (NERSA), http://www.nersa.org.za. Accessed 24 April 2013.

NPC, 2012, The National Development Plan 2030, The National Planning Commission (NPC), Office of the Presidency, Pretoria.

NRF, 2014, Research support and knowledge networking databases, http://stardata.nrf.ac.za/star/ccrpdlogin.html.

RSA, 2014, Draft position paper on the South African biofuels regulatory framework, *Government Gazette*, vol. 583, no. 37232, 15 January 2014, Department of Energy (DoE), Pretoria.

SETRM, 2014, South Africa solar energy technology road map, Draft document, Department of Science and Technology and the Department of Energy, Pretoria.

the dti, 2011, The South African renewables initiative: Partnering for green growth, Department of Trade and Industry (the dti), Pretoria, http://sarenewablesinitiative.wordpress.com/. Accessed 14 May 2014.

Turchi, C., Langley, N., Bedilion, R. and Libby, C., 2011, *Solar-augment potential of US fossil-fired power plants*, National Renewable Energy Laboratory (NREL) Technical report, NREL/TP-5500-50597, February 2011.

US EIA, 2012, *Technically recoverable shale oil and shale gas resources: An assessment of 137 shale formations in 41 countries outside the United State*, U.S. Energy Information Administration (EIA).

WBA, n.d., Biofuels for transport. World Bioenergy Association fact sheet, World Bioenergy Association, Stockholm, http://www.environmental-expert.com/news/new-fact-sheet-on-biofuels-for-transport-363676. Accessed 23 April 2014.

Appendix 1:
Biographies of Panel Members

Frederik van Niekerk (Chair) is Deputy Vice-Chancellor: Research, Innovation and Technology at the North-West University. He obtained his BSc (Mathematics, Applied Mathematics and Physics), Hons BSc (Applied Mathematics), MSc (Physics) and DSc (Reactor Science) at Potchefstroom University. He is a registered Professional Scientist with the South African Council for Natural Scientific Professions (SACNASP). His scientific work included work on neutron noise, condition monitoring systems and systems engineering. His career in innovation management and leadership includes academic and management positions at the North-West University and senior management positions at the South African Nuclear Energy Corporation, Denel Aviation and the Pebble-bed Modular Reactor.

Susan Harrison is Professor in the Department of Chemical Engineering, University of Cape Town and Director of the Centre for Bioprocess Engineering Research. She has 20 years of research experience in bioprocess engineering, gained in the industrial and academic arenas. Her research in biohydrometallurgy centres on metal extraction from sulphidic minerals through tank and heap bioleaching, sulphate reduction and acid mine drainage prevention. She collaborates actively with researchers at the University of Mumbai, Cambridge University and Imperial College, London and with companies in South Africa and abroad.

Nelson Ijumba was the Deputy Vice-Chancellor (Research) at the University of KwaZulu-Natal, responsible for knowledge production and innovation, and also a Professor of Electrical Engineering, specialising in high-voltage systems. He is currently at the University of Rwanda. He graduated from the University of Dar es Salaam (Tanzania), and obtained his Masters and doctoral degrees from the Universities of Salford and Strathclyde (United Kingdom), respectively. He is a senior member of the Southern African Institution of Electrical Engineers, a member of the Institute of Electrical and Electronics Engineers, and a member of the Institution of Engineering and Technology. He is a registered Professional Engineer with the Engineering Council of South Africa and a Chartered Engineer of the United Kingdom Engineering Council. He has over 30 years of experience in teaching, research, consulting and academic leadership. His research interests are in the areas of power and energy systems, impact of technologies on sustainable development and translation of research outputs into socially relevant innovative products. He has published widely and made presentations at international and local conferences.

Steve Lennon has been employed by Eskom since 1983 and has been Divisional Executive, Eskom International, since 2011. He obtained a BSc in Chemistry from Natal University; an MSc in Physical Metallurgy and PhD in Turbine Disc Cracking from the University of the Witwatersrand. He is recognised locally and internationally for leadership roles in technological innovation, sustainability management and the triple bottom line, global energy sector trends and policy, and climate change policy and strategy. He is currently responsible for international memberships and agreements, investor relations, international offices, climate change and renewables business.

Regina Maphanga is a Senior Researcher at the Materials Modelling Centre, University of Limpopo. She completed her PhD in Physics in 2005 at the University of Limpopo. Her research focuses on computational modelling of cathode materials for lithium-ion batteries for use in energy storage devices. In addition, she is appointed as a Junior Associate at the Abdus Salam International Centre for Theoretical Physics in Italy and a Science Advisor for Wiley Publishing. In 2011, she was selected by the InterAcademy Panel as a distinguished young scientist to represent South Africa during the World Economic Forum's Annual Meeting of the New Champions in China. Maphanga is a member of the South African Young Academy of Science and the Global Young Academy. She is the recipient of the 2009/10 NSTF research award for a distinguished young black female researcher over the last 2–5 years and recipient of the 2012 Distinguished Young Women Scientist in the Physical and Engineering Sciences for outstanding contribution in Science, Engineering and Technology.

Wikus van Niekerk is a Professor in the Department of Mechanical and Mechatronic Engineering and Director of the Centre for Renewable and Sustainable Energy Studies at Stellenbosch University. He is registered as a Professional Engineer with the Engineering Council of South Africa and currently evaluated by the NRF as a C2 internationally recognised researcher. He is regularly consulted by industry on a variety of areas, including noise and vibration, especially human response to noise and vibration, vehicle dynamics, renewable energy systems and wave energy.

Appendix 2: Questionnaire Used for Desktop Study

Dear Energy Researcher

RE: SURVEY ON THE STATE OF ENERGY RESEARCH IN SOUTH AFRICA

The Academy of Science of South Africa (ASSAf) invites all scientists working in the field of energy to participate in a survey of the State of Energy Research in South Africa.

The data gathered from this survey will contribute towards a multifaceted study that will assess the extent to which systems are in place to ensure high-quality and responsible energy research and will identify manners in which existing systems and measures may be strengthened.

The objective of the project is to provide an overview of current energy research being commissioned (the organisations involved and budgets allocated) and carried out at South African universities and universities of technology, science councils and the private sector to identify common themes and priorities in energy research, to identify possible gaps that are not being covered by current energy research, to compile a profile of the energy researchers actively working in the field and to make recommendations on future energy research focal areas for South Africa. Lastly, the project should investigate the budgetary allocation to energy research in South Africa, via the NRF and other public and private institutions.

ASSAf appeals to *energy scientists and energy managers* to complete this survey. It takes approximately 10 minutes and is entirely confidential.

The results of the survey will be saved in a database that will be securely stored at ASSAf and will not be distributed to any third party for commercial gain or for any other reason. As the official national science academy of South Africa, ASSAf strives to provide evidence-based scientific advice to the South African scientific and policy community.

Yours sincerely,

Professor Roseanne Diab
Executive Officer: Academy of Science of South Africa

Participant information

Please complete the following before you start with the survey:

1. Please type in your details:

   Title
   Name
   Surname

2. Please complete the following regarding the institution you work for:

   The name of your organisation
   The name of your business unit
   Your position within this organisation

3. In which category does your organisation fall?

   Academic Institution/Public industry/Private industry/Other (please specify)

4. In which of the following fields does your organisation conduct or commission

   Renewable Energy: (Bio-energy)
   Renewable Energy: (Sun, Wind, Ocean, Geothermal, other)
   Nuclear Energy
   Fossil based Energy (Coal, Oil, Gas)
   Energy Storage
   Energy Efficiency
   None of the above

5. Thank you for taking your time to complete this questionnaire, for future reference, please provide us with a list of the Energy-related fields that your organisation do conduct or commission research in. (Disqualification – Organisation not applicable)

6. May we contact you again in future for similar surveys? *Yes/No*

Participant screening

7. Are you the correct person within you organisation to answer this survey? (The person completing this should be able to provide information on Energy research at your institution in terms of: Research activity, resources, funding etc.) *Yes/No*

Disqualification – Participant not applicable

8. Please provide us with the name and contact details of another person within your organisation, who will be able to provide ASSAf with the needed information, in the comment box below. (e.g. Eugene Smith eugene.smith@assaf.co.za 0123456789 Fossil-based energy)

9. Thank you for taking your time to complete this questionnaire, for future reference, please provide us with a list of the Energy-related fields that your organisation do conduct or commission research in.

10. May we contact you again in future for similar surveys? *Yes/No*

Research activity

11. Please summarise your current Energy research activities by specifically referring to projects that your institution was involved in, in the past 5 years, as well as the key outputs (articles, conference papers, human resources, IP development etc.) of each activity during this period.

(E.g. our institution conducts research into the effect of temperature on the efficiency of solar cells. This research is conducted in collaboration with ABC Solar and the project is funded through the THRIP mechanism). This project has been going on for the past 5 years (since 2008). Outputs resulting from this project include: 4 journal articles, 5 conference papers, 2 Master's degree graduates and 1 Doctoral graduate.)

12. What barriers do you face in terms of your Energy research?

Funding
Infrastructure
Equipment
Human resources
Other (please specify)

13. In terms of the barriers you mentioned in the previous question, what are your requirements/needs in terms of Energy research? Please distinguish between short- and medium-term requirements/needs.

Sector selection

14. On which of the following sectors will you be providing information?

Renewable Energy: (Bio-energy)
Renewable Energy: (Sun, Wind, Ocean, Geothermal, other)
Nuclear Energy
Fossil-based Energy (Coal, Oil, Gas)
Energy Storage
Energy Efficiency
None of the above

Sector specific: Renewable Energy (Bio-energy)

15. In the Renewable Energy: (Bio-energy) sector, what are the major fields of energy research that your organisation conducts/commissions research in?

Microalgae to Energy
Macroalgae to
Waste to
Food Crops to Energy
Nonfood Crops to Energy
Bioalcohols
Biohydrogen
Biogas
Biodiesel
Syngas
Bio-oil
Other (please specify)

16. Why are you conducting/commissioning research in these specific Bio-energy fields?

17. What future plans do you have regarding bio-energy research, either in current fields or in new fields?

18. What Bio-energy Energy projects have you taken up and which projects had to be abandoned maybe due to lack of funding etc.

19. Do you have any recommendations on future energy research focal areas?

20. Please describe the research infrastructure (hardware, software, support staff and other resources) for energy research available at your organisation.

21. Who are your key collaborators in this sector? Please indicate the specific field within the sector (biodiesel, bioether, syngas etc.), the type of organisation (academic institution, public industry, private industry), level of collaboration (national/international) as well as the name of the organisation for each collaborator. (E.g. Biodiesel Private industry International Agrip)

22. Please provide us with the names, contact details, highest qualification and fields of the active researchers in this sector (Bio-energy) at your organisation.

Sector specific: Renewable Energy (Sun, Wind, Ocean, Geothermal, Other)

23. In the Renewable Energy: (Sun, Wind, Ocean, Geothermal, Other) sector, what are the major fields of energy research that your organisation conducts/commissions research in?

    Alternative Transportation
    Carbon Emissions
    GeoThermal Energy
    Hydro
    Hydrogen Economy
    Oceancurrent Energy
    Photovoltaic Systems
    Solar Thermal Energy
    Solar Water Heaters
    Wave Energy
    Wind Energy
    Other (please specify)

24. Why are you conducting/commissioning research in these specific Renewable?

25. What future plans do you have regarding energy research, either in current fields or new fields?

26. What Renewable Energy projects have you taken up and which projects had to be abandoned maybe due to lack of funding etc.

27. Do you have any recommendations on future energy research focal areas?

28. Please describe the research infrastructure (hardware, software, support staff and other resources) for energy research available at your organisation.

29. Who are your key collaborators in this sector? Please indicate the specific field within the sector (wave/solar/wind etc.), the type of organisation (academic institution, public industry, or private industry), level of collaboration (national/international) as well as the name of the organisation for each collaborator. (E.g. Solar Private industry International Sun Farming)

30. Please provide us with the names, contact details, highest qualification and fields of the active researchers in this sector (Renewable Energy) at your organisation.

Sector specific: Nuclear Energy

31. In the Nuclear Energy sector, what are the major fields of energy research that your organisation conducts/commissions research in?

    Nuclear fuel cycles
    Nuclear policy
    Nuclear safety
    Process heat applications
    Reactor analysis and design
    Thermal fluid systems
    Other (please specify)

32. Why are you conducting/commissioning research in these specific Nuclear Energy fields?

33. What future plans do you have regarding Nuclear Energy research, either in current fields or new fields?

34. What Nuclear Energy projects have you taken up and which projects had to be abandoned maybe due to lack of funding etc. (i.e. Please provide a listing of both successful and unsuccessful projects/research activities, as well as the reasons why it was either successful or unsuccessful.)

35. Do you have any recommendations on future energy research focal areas? Please list them.

36. Please describe the research infrastructure (hardware, software, support staff and other resources) for energy research available at your organisation.

37. Who are your key collaborators in this (Nuclear Energy) sector? Please indicate the specific field within the sector (safety, policy etc.), the type of organisation (academic institution, public industry or private industry), level of collaboration (national/international) as well as the name of the organisation for each collaborator. (E.g. Solar Private industry International Sun Farming)

38. Please provide us with the names, contact details, highest qualification and fields of the active researchers in this sector (Nuclear Energy) at your organisation.

Sector specific: Fossil-based Energy (Coal, Oil, Gas)

39. In the Fossil-based Energy sector, what are the major fields of energy research that your organisation conducts/commissions research in?

    Coal
    Oil
    Gas
    Other (please specify)

40. Why are you conducting/commissioning research in these specific Nuclear Energy fields?

41. What future plans do you have regarding Fossil-based Energy research, either in current fields or new fields?

42. What Fossil-based Energy projects have you taken up and which projects had to be abandoned maybe due to lack of funding etc. (i.e. Please provide a listing of both was either successful or unsuccessful.)

43. Do you have any recommendations on future energy research focal areas?

44. Please describe the research infrastructure (hardware, software, support staff and other resources) for energy research available at your organisation.

45. Who are your key collaborators in this sector? Please indicate the specific field within the sector the type of organisation (academic institution, public industry, or private industry), level of collaboration (national/international) as well as the name of the organisation for each collaborator. (E.g. Solar Private industry International Sun Farming)

46. Please provide us with the names, contact details, highest qualification and fields of the active researchers in this sector (Fossil based Energy) at your organisation.

Sector specific: Energy Storage

47. In the Energy Storage sector, what are the major fields of energy research that your organisation conducts/commissions research in?

    Mechanical Storage
    Electromagnetic Storage
    Chemical Storage
    Electrochemical Storage
    Biological Storage
    Thermal Energy Storage
    Alternative Transportation
    Other (please specify)

48. Why are you conducting/commissioning research in these specific Energy Storage fields?

49. What future plans do you have regarding Energy Storage research, either in current fields or new fields?

50. What Energy Storage projects have you taken up and which projects had to be abandoned maybe due to lack of funding etc.

51. Do you have any recommendations on future energy research focal areas?

52. Please describe the research infrastructure (hardware, software, support staff and other resources) for energy research available at your organisation.
    Hardware – Software – Support staff – Other (please specify)

53. Who are your key collaborators in this (Energy Storage) sector? Please indicate the specific field within the sector (Electrochemical Storage/Biological Storage/Thermal Energy Storage etc.), the type of organisation (academic institution, public industry, private industry), level of collaboration (national/international) as well as the name of the organisation for each collaborator. (E.g. Solar Private industry International Sun Farming)

54. Please provide us with the names, contact details, highest qualification and fields of the active researchers in this sector (Energy Storage) at your organisation.

Sector specific: Energy Efficiency

55. In the Energy Efficiency sector, what are the major fields of energy research that your organisation conducts/commissions research in?

    Energy Efficient buildings
    Passive Architecture
    Smart Windows
    Energy Efficient Devices/appliances
    Other (please specify)

56. Why are you conducting/commissioning research in these specific Energy Efficiency fields?

57. What future plans do you have regarding Energy Efficiency research, either in current fields or new fields?

58. What Energy Efficiency projects have you taken up and which projects had to be abandoned maybe due to lack of funding etc.

59. Do you have any recommendations on future energy research focal areas?

60. Please describe the research infrastructure (hardware, software, support staff and other resources) for energy research available at your organisation.

61. Who are your key collaborators in this (Energy Efficiency) sector? Please indicate the specific field within the sector (Energy efficient buildings etc.), the type of organisation (academic institution, public industry or private industry), level of collaboration (national/international) as well as the name of the organisation for each collaborator. (E.g. Solar Private industry International Sun Farming)

62. Please provide us with the names, contact details, highest qualification and fields of the active researchers in this sector (Energy Efficiency) at your organisation.

Funding

63. How much did your organisation spend (on average) on Energy research per year, in the past 5 years?

    In total in terms of Energy Research
    Renewable Energy: (Sun, Wind, Ocean, Geothermal, other)
    Renewable Energy: (Bi-energy)
    Nuclear Energy
    Fossil based Energy (Coal, Oil, Gas)
    Energy Storage
    Energy Efficiency

64. Who are the major funders of the energy research that your organisation conducts/commissions? Please provide the sector, the names of the organisations and the amount they provided this year and the previous year. E.g. Solar energy research: TIA (Government) 2012: R200 000 2013: R400 000 SASOL (Public Industry) 2012: R50 000 2013 – Sun Farming (Private International industry) 2012: – 2013 R25 000.

65. What are the benefits the funders foresee in commissioning and funding this research?

Human resource development
IP development
Publications
Products
Other (please specify)

Thank you for completing this survey

Thank you for taking your time to complete this questionnaire, for future reference, please provide us with a list of the OTHER Energy-related fields that your organisation conduct or commission research in.

May we contact you again in future for similar surveys? Yes/No

End – Thank you

If you have any queries regarding this study, please contact:

Henriette Wagener

Communication Officer/Programme Officer: Environment, Water and Energy
Academy of Science of South Africa (ASSAf)
Tel: +27 12 349 6617
communications@assaf.org.za

Appendix 3:
Questionnaire Statistics

1. Background

The questionnaire was sent to the 23 public higher education institutions, as well as to private and public organisations which conduct or have a mandate to conduct energy or energy-related research. These organisations were identified based on the desktop study, as well as knowledge of the panel and researchers.

The survey was implemented online using Survey Monkey. An overview of the process and the responses are presented here.

2. Objectives

The objective of the survey is to provide an overview of current energy research being commissioned (the organisations involved and budgets allocated) and carried out at South African universities and universities of technology and public and private organisations with a known energy research agenda; to identify common themes and priorities in energy research; to identify possible gaps that are not being covered by current energy research; to compile a profile of the energy researchers actively working in the field; and to make recommendations on future energy research focal areas for South Africa.

The survey comprised four parts:

- A participant screening part to determine whether the state institution conducts or commissions energy-related research and/or to establish whether the correct contact person within the institution had been identified.
- A general energy research section, where specific sectors in which the institutions are active are identified and resources, infrastructure available and barriers to energy-related research could be identified.
- A sector-specific part, where more information on the specific research being commissioned or conducted could be provided.
- A funding part, where all the funding-related issues of the research commissioned and/or conducted could be reported.

3. Methodology

The questionnaire was piloted with an independent researcher and went through a number of iterations until the final version (Appendix 2) was approved by the panel. In view of time constraints, Deputy Vice-Chancellors (DVCs) responsible for research at each of the academic institutions in the country were targeted as the first point of contact. In addition, senior management at public and private organisations with a known energy agenda, were contacted, with a request to delegate the survey to relevant managers and/or researchers within their organisation who would be able to complete the survey on behalf of their institution.

At first, the response rate of participants was very low. Personal contacts were used to increase the responses, but there are still some organisations that have not responded.

4. Overview of Responses

Data were collected over three months, from December 2013 to mid-March 2014. Since this was an online survey, participants could complete the survey at their leisure. Reminders were sent to non-respondents on a two-weekly basis. More than 100 potential participants were approached, 71 of whom responded. In 81% of cases the survey reached the appropriate person within the organisation, and in the remainder, where the participant was not the correct person to complete the survey, their suggestion of a more suitable candidate was used to approach an alternative participant for that organisation.

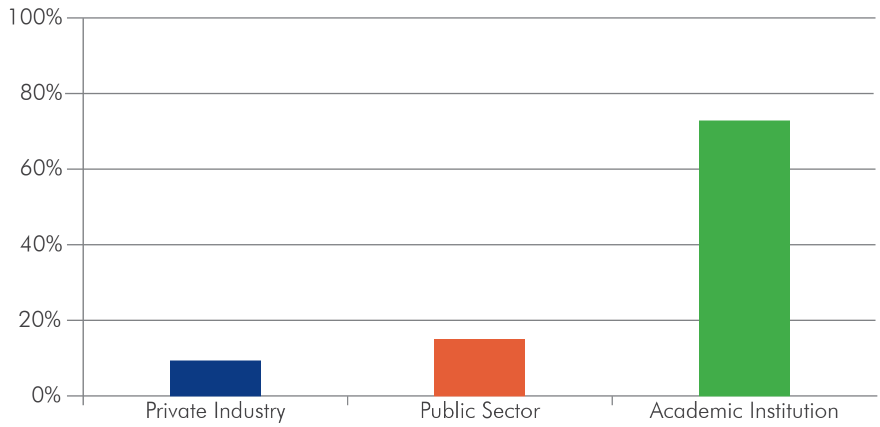

Figure 1: Organisational categories of participants

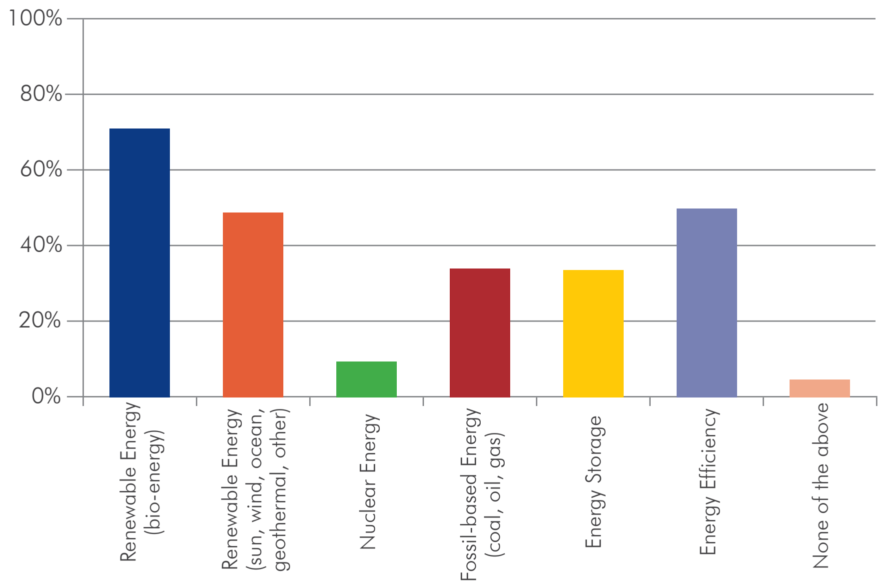

Figure 2: Energy research sectors of interest to participating institutions

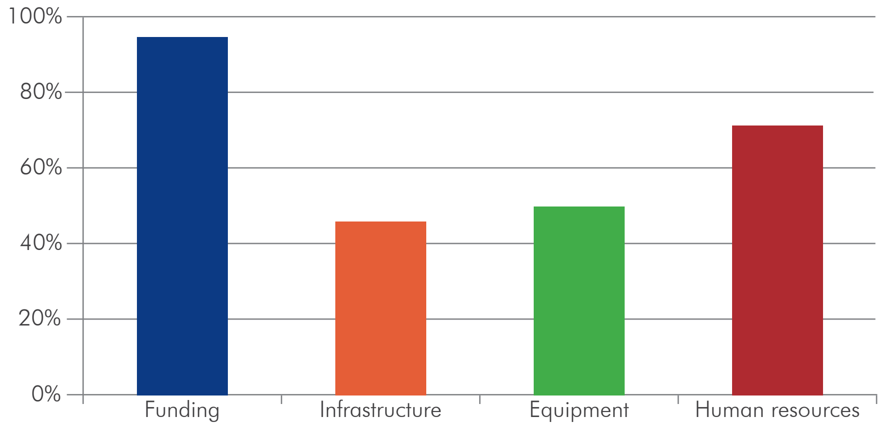

Figure 3: Barriers to research

Appendix 4:
Masters and Doctoral Degrees in Energy and Energy-related Themes, 2006–2013

(Source: NRF, 2014)

HEI	Degree type	Year competed	Title	Authors
Da Vinci	Masters	2007	Developing a process ensuring quality project management of power stations	Prinsloo W (Werner)
Da Vinci	Masters	2008	Towards developing a new model for the pricing of electrical energy in continuously changing environments	Naidoo P (Pathmanathan)
Da Vinci	Masters	2010	Flue gas desulphurisation technologies and coal fired power stations: an Eskom survey	Dhaver-Young K (Karmatchee)
Da Vinci	Masters	2010	The management of records information: a South African energy utility industry survey	Fourie L (Leon)
Da Vinci	Masters	2011	Prepaid electricity revenue management: using technology and innovation to reduce prepaid meter tempering	Mutono A (Allen)
Milpark Business School	Masters	2013	Investigate the viability of commercialisation of hydrogen fuel cell vehicles	Hunter GJ (Graham John)
CPUT	Doctoral	2010	Electrical energy management and its impact in sub-Saharan Africa	Mohamed AK (Afua Khalfan)
CPUT	Masters	2009	Modelling and development of fuel cell off-grid power converter system	Raji AK (Atanda Kamoru)
CPUT	Masters	2010	Development of a digital energy-meter with error compensation for utility and management	O'Çonnell DP (Daniel Paul)
CPUT	Masters	2010	Power system management under abnormal network conditions	Hull MH (Marius Heinrich)
CPUT	Masters	2011	Development of a generic digital controller for power electronic applications	Jooste CR (Charl Roelof)
CUT	Masters	2010	Energy efficiency interventions for residential buildings in Bloemfontein using passive energy techniques	Kumirai T (Tichaona)
CUT	Masters	2013	Synthesis and characterisation of pt-alloy oxygen reduction electrocatalysts for low temperature pem fuel cells	Mohamed R (Rhiyaad)
DUT	Masters	2009	Design and analysis of a stand-alone hybrid photovoltaic-based power system	Dusabe D (Deo)
NMMU	Doctoral	2009	Development of a reciprocating aerofoil wind energy harvester	Phillips RL (Russell Leslie)
NMMU	Masters	2006	On the characterisation of copper indium diselenide based photovoltaic devices	Thantsha NM (Nicolas Matome)
NMMU	Masters	2011	An economic evaluation of a wind power electricity generating farm in South Africa	Menzies GH (Greig Hamilton)
NMMU	Masters	2012	Influence of legislation and policy on the implementation of renewable energy projects in the Nelson Mandela Bay Municipality	Mkhonta GT (Gcebekile Tikhokhile)
NMMU	Masters	2012	Statistical tools for wind energy potential	Ndzukuma DS (Doctor Sibusiso)

HEI	Degree type	Year competed	Title	Authors
NMMU	Masters	2013	Evaluate effectiveness of think blue factory strategy on effective energy management in Volkswagen Group South Africa	Mahlati A (Andile)
NMMU	Masters	2013	Towards integrated catchment management: challenges and opportunities surrounding implementation in the Gamtoos power catchment	Materechera F (Fenji)
NMMU	Masters	2013	Statistical model for risk diversification in renewable energy	Ahame E (Edmund)
NMMU	Masters	2013	Weather neutral models for short-term electricity demand forecasting	Nyulu T (Thandekile)
NMMU	Masters	2013	Evaluation for harnessing low-enthalpy geothermal energy in South Africa based on a model pilot plant in the Limpopo belt	Dhansay TG (Taufeeg Goolam)
NMMU	Masters	2013	Renewable energy as an alternative resolution in the Buffalo City Metropolitan Municipality	Maqaqa MC (Xolile Donaldson)
NWU	Doctoral	2006	A calibration neutron monitor for long-term cosmic ray modulation studies	Krüger H (Helena)
NWU	Doctoral	2007	An investigation into the DSM and energy efficiency potential of a modular underground air cooling unit applied in the South African mining industry	Van Eldik M (Martin)
NWU	Doctoral	2007	Monitoring the levels of toxic metals of atmospheric particulate matter in the North West Province	Kgabi NA (Nnenesi Anna)
NWU	Doctoral	2008	Health monitoring of a Brayton-cycle-based power conversion unit	Du Rand CP (Carel Petrus)
NWU	Doctoral	2009	A unique energy efficiency investment decision model for energy services companies	Bert GD (Gerhardus Derk)
NWU	Doctoral	2011	Thermal modelling of a high speed permanent magnet synchronous machine	Grobler AJ (Andries Johannes)
NWU	Masters	2006	The licensing responsibilities for the Pilot Fuel Plant (PFP) in ensuring safety as required by the National Nuclear Regulator (NNR) in order to obtain an operating license	Mocwaledi PK (Percival Kgothatso)
NWU	Masters	2007	Research into real time energy management on gold mines	De Lange NL (Nico Louis)
NWU	Masters	2007	The implementation of urban greening projects for energy efficiency and greenhouse gas reduction in Potchefstroom, South Africa	Nel G (Guillaume)
NWU	Masters	2007	Search for periodicity in emission of very high energy gamma-rays from the supernova remnant MSH 15-52	Davids ID (Isak Delberth)
NWU	Masters	2007	Control of an underground rock winder system to reduce electricity costs on RSA gold mines	Vosloo JC (Jan Corne)
NWU	Masters	2008	Demand side energy management of a cascade mine surface refrigeration system	Schutte AJ (Abraham Jacobus)
NWU	Masters	2008	Xenon-induced axial power oscillations in the 400 MW pebble modular reactor	Strydom G (Gerhard)
NWU	Masters	2008	Development of a flywheel energy storage system	Janse van Rensburg JJ (Jan Jacobus)
NWU	Masters	2009	Energy savings through control of underground compressed air	Neser H (Henri)
NWU	Masters	2009	Simulation of the irradiation behaviour of the PBMR fuel in the SAFARI-1 reactor	Makgopa BM (Bessie Mmakgoto)
NWU	Masters	2009	Comparative cost-benefit analysis of renewable energy resources for rural community development in Nigeria	Ogunlade AA (Abimbola Adegoke)
NWU	Masters	2009	Critical analyses of the used and spent fuel storage facility of the 400 MWth PBMR plant	Kaisavelu A (Anand)

HEI	Degree type	Year competed	Title	Authors
NWU	Masters	2010	Energy efficiency opportunities in mine compressed air systems	Schroeder FW (Frederick William)
NWU	Masters	2010	Maintenance management for effective operations management at Matimba Power Station	Mutloane OE (Oufa Ernest)
NWU	Masters	2010	Design of a model of a combined cycle power plant for the PBMR	Laurens R (Roelf)
NWU	Masters	2010	Thermal-fluid analysis of various indirect and combined cycle power concepts for a HTGR	Dreyer J (Jacques)
NWU	Masters	2010	Validation of a biomass project in a rural community in Nigeria	Njoku PO (Paul Okechukwu)
NWU	Masters	2011	Development and adaptation of dynamic models for new power generation sources	Grobler JH (Johannes Hendrick)
NWU	Masters	2011	Development of an energy management solution for mine compressor systems	Du Plessis JN (Johan Nicolaas)
NWU	Masters	2011	A framework for building confidence in nuclear power for the labour Union environment of South Africa	Maharaj S (Suraksha)
NWU	Masters	2011	Comparative study between a two-group and a multi-group energy dynamics code	Pretorius L (Louisa)
NWU	Masters	2011	Development of an unloading machine for nuclear fuel pebbles	Drijfhout F (Folkert)
NWU	Masters	2011	Parametric study of thorium fuel cycles in a 100 MWth pebble bed high temperature reactor	Panday F (Farisha)
NWU	Masters	2011	Signature analysis of the primary components of the Koeberg nuclear power station	Bezuidenhout JA (Jandrê Albert)
NWU	Masters	2011	The influence of the number of fuel passes through a pebble bed core on the coupled neutronics/thermal-hydraulics characteristics	Geringer JW (Josna Wilhelmina)
NWU	Masters	2011	Thermal fluid analysis of combined power and desalination concepts for a high temperature reactor	Nel R (Ryno)
NWU	Masters	2011	Thorium-based fuel cycles: saving uranium in a 200 MWth (MegaWatt Thermal) pebble bed high temperature reactor	Gintner SK (Stephan Konrad)
NWU	Masters	2011	Thermo hydraulic analysis of the PBMR fuel handling and storage system	Le Roux PL (Philip Louis)
NWU	Masters	2012	Implementing energy efficiency measures on the compressed air network of old South African mines	Scheepers CF (Christiaan Frederick)
NWU	Masters	2012	An energy efficient mass transportation model for Gauteng	Nassiep KM (Kadri Middelekop)
NWU	Masters	2012	The assessment of waveform distortion in power systems: validation of methods based on single-point measurement	Serfontein D (Duan)
NWU	Masters	2012	A benchmarking model for harmonic distortion in a power system	Rudolph J (Johnny)
NWU	Masters	2012	Evaluation of the reduction of CO_2 emissions from a coal-to-liquid utilities plant by incorporating PBMR energy	Gouws MM (Marizanne Michele)
NWU	Masters	2012	Model predictive control of a Brayton cycle-based power plant	Lusanga PK (Peter Kabanda)
NWU	Masters	2012	Modelling of fission product release from Triso fuel during accident conditions: benchmark code comparison	Ramlakan AJ (Alastair Justin)
NWU	Masters	2012	Optimisation of wind turbine electrical power conversion	Van Wyngaardt Q (Quintin)
Rhodes	Doctoral	2010	Harvesting strategies of fuel wood and kraalwood users at Machibi: identifying the driving factors and feedbacks	Scheepers KJ (Kelly Juliet)

HEI	Degree type	Year competed	Title	Authors
Rhodes	Masters	2007	Particle precipitation effects on the ionosphere	Sibanda P (Patrick)
Rhodes	Masters	2011	Nanostructures and metallophthalocyanines: applications in microbial fuel cells	Edwards SL (Sean Leonard)
TUT	Doctoral	2011	Production of biodiesel fuel from non-edible oils	Kafuku GM (Gerald Majella)
TUT	Doctoral	2013	Analysis of wind energy resource and impacts of its integration into power systems	Ayodele TR (Temitope Raphael)
TUT	Masters	2008	Woodchips as carbon and energy source for denitrification	Tjatji MP (Martin Phalane)
TUT	Masters	2010	Effects of fuel blends containing croton oil, butanol and diesel on the performance and emissions of diesel engines	Lujaji F (Frank)
TUT	Masters	2010	Photo-assisted biodegradation of halogenated breakdown products from nuclear fuel recovery process water	Makgato SS (Seshibe Stanford)
TUT	Masters	2010	Evaluation of biodiesel from used cooking sunflower oil as substitute fuel	Steyn CB (Christoffel Bernardus)
TUT	Masters	2010	The design and evaluation of a solar-powered absorption refrigerator for African conditions	Nwamba KJ (Khombomuni Jerry)
TUT	Masters	2012	Modelling and simulating of hydrogen storage device for fuel cell plant	Akanji OL (Olaitan Lukman)
TUT	Masters	2013	Efficiency of household water treatment devices/systems in removing pathogenic bacteria causing gastrointestinal diseases	Mwabi JK (Jacelyne Kamwanya)
TUT	Masters	2013	Nonlinear modelling and control of a thyristor-controlled series capacitor for power enhancement	Anele AO (Amos Onyedikachi)
TUT	Masters	2013	A versatile platform for matrix converters for small-scale wind power integration	Ehlers PJ (Pieter Johannes)
TUT	Masters	2013	Charging of lithium-ion batteries with a hydrogen fuel cell for electrical bicycles	Monjaux ACJJ (Aurelien Clement Jean Joseph)
UCT	Doctoral	2006	Energy policies for sustainable development in South Africa's residential and electricity sectors: implications for mitigating climate change	Winkler HE (Harald Ernst)
UCT	Doctoral	2007	Clustering algorithms for sensor networks and mobile ad hoc networks to improve energy efficiency	Wei D (Dali)
UCT	Doctoral	2009	Stabilising an islanded nuclear power plant with a high-energy resistor	Lilje P (Peter)
UCT	Doctoral	2010	High speed flywheel and test rig design for rural energy storage	Okou R (Richard)
UCT	Masters	2006	Mac and physical layer energy efficiency for ad hoc wireless sensor networks	Basich ZLJ (Zoran Luka Josip)
UCT	Masters	2006	A theoretical assessment of fuel combustion attributes to enhance the operational envelope of HCCI engine	Londleni SC (Sibusiso Cydwell)
UCT	Masters	2007	Multi-agent analysis of industrial networks: a South African bio-energy case study	Malan R (Rene)
UCT	Masters	2009	Evaluation and mitigation of the undesired effect of DC bias on inverter power transformer	Isumbingabo EF (Emma Francoise)
UCT	Masters	2009	Energy from waste as a renewable energy supply to supplement electricity in South Africa	Dowling SL (Sarah Lea)

HEI	Degree type	Year competed	Title	Authors
UCT	Masters	2009	Financial power and monetary regionalism: the political economy of European Monetary Union after the end of the Bretton Woods financial system	De Masi FVL (Fabio Valeriano Lanfranco)
UCT	Masters	2009	The design of a combustion test facility for synthetic jet fuel research	Burger VB (Victor Barend)
UCT	Masters	2009	An analysis into the geophysical and industrial requirements, if South Africa were to evolve its electricity supply to a large emphasis on concentrated solar power	Morse WJ (Warren James)
UCT	Masters	2009	Impact of wind generators on a power system's transient stability	Khomari M (Moloantoa)
UCT	Masters	2010	Effective implementation of energy efficiency in the South African residential sector	Nyatsanza KS (Kudakwashe Stephen)
UCT	Masters	2010	Determining the impacts of residential energy policies on Gauteng's tool for residential energy consumption and the associated emissions using LEAP as a tool for analysis	Senatla M (Mamahloko)
UCT	Masters	2010	The role of industrial policy in pursuing climate change mitigation objectives in South Africa	Burton JAS (Jesse Alexandra Sarah)
UCT	Masters	2010	The effect of energy input on precipitation in an oscillating grid reactor	Mokgethi BT (Botlhe Tshimologo)
UCT	Masters	2010	Implication of national policy on electricity distribution planning in Kenya	Saulo MJ (Michael Juma)
UCT	Masters	2010	Renewable energy legislation in South Africa: a critical comparative analysis with the USA	Jooste DB (Dustin Bradford)
UCT	Masters	2010	Anaerobic digestion of algal biomass: a feasibility study for bioenergy production	Inglesby AE (Alister Edward)
UCT	Masters	2010	Availability and affordability of IPP wind power project financing in South Africa	White JAD (James Alexander Dolin)
UCT	Masters	2010	Challenges facing the wind energy industry in South Africa	Waller MK (Mary Kate)
UCT	Masters	2010	Integration of wind energy systems into the grid: power quality and technical requirements	Madangombe TT (Taruziwa Trainos)
UCT	Masters	2010	Dynamic modelling and emulation of a high temperature proton exchange membrane fuel cell (HT PEMFC)	De Beer C (Chris)
UCT	Masters	2011	The role of market-based instruments that use existing markets to promote energy efficiency in South African industry	Cargill JG (Judith Greer)
UCT	Masters	2011	Greenhouse gas mitigation cost of energy from biogas: a techno-economic analysis of co-digestion of three types of waste in Cape Town	Malla L (Lesego)
UCT	Masters	2011	A software tool for the preliminary performance modelling of central receivers and associated power cycles	Smith LM (Lee Matthew)
UCT	Masters	2011	Power management of a 1kW HTPEMFC-based CHP system	Reddy D (Direshni)
UCT	Masters	2011	A techno-economic study of energy efficiency and renewable energy technologies for supermarkets in South Africa	Pather-Elias S (Simisha)
UCT	Masters	2011	Design of a small-scale sustainable wind energy conversion system	Jagau H (Hartmut)
UCT	Masters	2011	Do solar water heaters improve access to hot water and reduce electricity costs? The complexities of implementing energy poverty interventions in South African townships: a case study of Nyanga township	Maboda S (Sivuyile)
UCT	Masters	2011	Optimal sizing of hybrid renewable energy systems for rural electrification	Coppez G (Gabrielle)

HEI	Degree type	Year competed	Title	Authors
UCT	Masters	2011	Site location and techno-economic analysis of utility-scale concentrating solar power plants in South Africa	Brodrick JJL (Joshua James Lawrence)
UFH	Masters	2006	Design and implementation of an automated photovoltaic module current-voltage tester employing a variable power supply unit	Simon M (Michael)
UFH	Masters	2007	Photovoltaic powered wireless communication system for rural schools outside national utility grid	Kaseke R (Richmore)
UFH	Masters	2008	Land distribution, ecological sustainability and impact mitigation in Zimbabwe: the case of Makarora farm in Mashoneland east	Mubiwa B (Brian)
UFS	Doctoral	2006	The role of lipids in the flocculation of Saccharomyces cerevisiae	Strauss CJ (Catharina Johanna)
UFS	Masters	2006	Influence of the shape and size of a quantum structure on its energy levels	Harris RA (Richard Anthony)
UJ	Doctoral	2008	The use of supply chains and supply chain management to improve the efficiency and effectiveness of GIS units	Schmitz PMU (Peter Maria Urban)
UJ	Doctoral	2008	Modelling real-world driving, fuel consumption and emissions of passenger vehicles: a case study in Johannesburg	Goyns PH (Philip Hugh)
UJ	Doctoral	2008	Evaluation of spent nuclear fuel management options for South Africa	Twala VG (Vusumuzi Glen)
UJ	Masters	2007	The efficiency of some structures to prevent soil erosion: a ase study in Mabula Private Game Reserve	Beringer GB (Grant Bill)
UJ	Masters	2007	Some Southern African perspectives on the remediation of hydrocarbon contaminated petroleum storage depots	Serrurier MHG (Marc Hal Gibbon)
UJ	Masters	2009	Failure analysis and risk management of power transformers within South Africa's transmission network	Dolly B (Bianca)
UKZN	Doctoral	2007	Modelling and analysis of inverter-based facts devices for power system dynamic studies	Huang F-W (Feng-Wei)
UKZN	Masters	2006	The impact of electricity as a source of energy: a demand side management perspective	Chetty N (Nalandran)
UKZN	Masters	2006	Analysis of the impact of closed-loop flow control strategies on power system stability characteristics	Ally A (As'Ad)
UKZN	Masters	2006	Enhancing the transient stability of power systems using a thyristor controlled series capacitor	Pillay Carpanen R (Rudy)
UKZN	Masters	2006	The disposal of spent nuclear fuel in South Africa: evaluation of technical and socio-political considerations	Twala VG (Vusumuzi Glen)
UKZN	Masters	2006	A data acquisition and control system for a Solar Thermal Energy Storage (TES) and Cooking System	Mawire A (Ashmore)
UKZN	Masters	2006	The spatial modelling and dynamics of a PV-powered fuel cell generator for renewal energy application	Bello MM (Mahood Mobolaji)
UKZN	Masters	2007	The free basic electricity policy: a case study of policy implementation in the Msunduzi municipality	Chetty I (Indrasen)
UKZN	Masters	2007	Renewable energy strategies for low-cost housing in South Africa: case studies from Cape Town	Dubbeld EJ (Elizabeth Jane)
UKZN	Masters	2010	Solar water heating: reducing the barriers	Naicker JS (Jayson Shirinivasan)
UKZN	Masters	2010	The development of a latent heat thermal energy storage system using a phase change	Zulu NM (Njabulo Mziwandile)
UL	Masters	2011	Management of electricity usage by household customers	Mmatola TG (Thaloki Gerald)

HEI	Degree type	Year competed	Title	Authors
Unisa	Masters	2007	Determination of Polycyclic Aromatic Hydrocarbons (PAHs) resulting from wood storage and treatment facilities for electricity transmission in Swaziland	Van Zuydam CS (Constance Sthembile)
University of Venda	Doctoral	2010	Computational study of the molecules of selected acylated phloroglucinols in vacuo and in solution	Kabanda MM (mwombeki Mwadham)
UP	Doctoral	2006	Energy emissions input-output analysis in South Africa	Moodley S (Shomenthree)
UP	Doctoral	2008	Efficiency and equity consideration in modelling inter-sectoral water demand in South Africa	Juana JS (James Sharka)
UP	Doctoral	2008	Energy substitution and options for carbon dioxide mitigation in Nigeria: an econometric approach	Adeyemo OO (Oyenike Olubukania)
UP	Doctoral	2009	Modelling silver transport in spherical HTR fuel	Van Der Merwe JJ (Jacobus Johannes)
UP	Doctoral	2010	Implications of voluntary reductions in energy-related emissions on the environment and economic welfare in Malawi: an environmental general equilibrium approach	Banda BM (Benjamin Mattondo)
UP	Doctoral	2011	A sectorial benchmark and trade system to improve electricity efficiency in South Africa	Inglesi-Lotz R (Roula)
UP	Doctoral	2012	Wind power resource assessment, design of grid-connected wind farm and hybrid power system	Rehman S (Shafiqur)
UP	Masters	2006	Selection of air pollution control technologies for power plants, gasification and refining processes	Van Greunen L-M (Larey-Marie)
UP	Masters	2008	Eradication of storage insect pests in maize using microwave energy and the effects of the latter on grain quality	Fakude MP (Moelo Patience)
UP	Masters	2011	Optimal sizing and operation of pumping systems to achieve energy efficiency and load shifting	Zhamh H (He)
UP	Masters	2011	Modelling, validation and control of an industrial fuel gas blending system	Muller CJ (Cornelius Jacobus)
UP	Masters	2011	Mixture models based on power means and generalised Q-fractions	Ackermann MH (Maria Helena)
UP	Masters	2011	Maximum net power output from an integrated design of a small-scale open and direct solar thermal Brayton cycle	Le Roux WG (Willem Gabriel)
UP	Masters	2012	Comparison of the performance of two atmospheric dispersion models (AERMOD and ADMS) for open pit mining sources of air pollution	Neshuku MN (Martha Nyambali)
UP	Masters	2012	The effect of tree size and bundle size on the productivity and costs of cut-to-length and full-tree multi-stem harvesting systems in Eucalyptus pulpwood	McEwan AM (Andrew Mark)
SU	Doctoral	2006	The effect of fuel formulation on the exhaust emissions of spark ignition engines	Bell A (Arthur)
SU	Doctoral	2007	Optimisation and control of a large-scale solar chimney power plant	Pretorius JP (Johannes Petrus)
SU	Doctoral	2012	Ecotoxity and environmental fate of diesel and diesel blends produced by Fischer-Tropsch processes using natural gas and coal as well as biodiesel and biodiesel blends	Alberus RMC (Randal Marius Colin)
SU	Doctoral	2012	Technology assessment of renewable energy sustainability in South Africa	Musango JK (Josephine Kaviti)
SU	Doctoral	2013	Development of a novel air-cored permanent magnet linear generator for direct drive ocean wave energy converters	Vermaak R (Rieghard)

HEI	Degree type	Year competed	Title	Authors
SU	Masters	2006	Aerodynamic optimisation of a small-scale wind turbine blade for low wind speed conditions	Cencelli NA (Nicolette Arnalda)
SU	Masters	2006	Namibian democracy: consolidated?	Kangas L (Lari)
SU	Masters	2006	Numerical modelling and experimental investigation of the flow and thermal processes in a motor car vehicle underhood	Van Zyl JM (Josebus Maree)
SU	Masters	2006	Steam jet ejector cooling powered by low grade waste or solar heat	Meyer AJ (Adriaan Jacobus)
SU	Masters	2006	Technical and economic evaluation of the utilisation of solar energy at South Africa's Sanae IV Base in Antarctica	Olivier JR (Jürgen Richter)
SU	Masters	2006	Urban water security in the city of Windhoek	Van Rensburg F (Francois)
SU	Masters	2006	The evaluation of the ONIOM-EE method for the QM/MM hybrid modelling of HF, CO and CO/HF clusters	Crous W (Werner)
SU	Masters	2006	Urban water security in the city of Windhoek	Van Rensburg F (Francois)
SU	Masters	2007	Dynamics and energy management of electric vehicles	Van Schalkwyk DJ (Daniel Jacobus)
SU	Masters	2007	An examination of ethanol gelfuel as a sustainable alternative to fossil fuel use in informal settlements	Jackson N (Neil)
SU	Masters	2007	The determination of cis and trans fatty acid isomers in partially hydrogenated plant oils	Marais C de W (Christiaan de Wet)
SU	Masters	2007	Evapotranspiration effects on air flowing over grass in a small glass roofed tunnel	Westdyk D (Dimitra)
SU	Masters	2007	Performance trends of an air-cooled steam condenser under windy conditions	Van Rooyen JA
SU	Masters	2007	Second order analyses methods for stirling engine design	Snyman H
SU	Masters	2008	The specification of a small commercial wind energy conversion system for the South African Antarctic research base SANAE IV	Stander JN (Johan Nico)
SU	Masters	2008	Turbine layout for and optimisation of solar chimney power conversion units	Fluri TP (Thomas Peter)
SU	Masters	2012	A study of current and possible future industrial engineering methodologies used to increase energy efficiency	Van der Merwe E (Este)
SU	Masters	2012	Development of an interactive energy management web application for residential end users	Du Preez C (Catharina)
SU	Masters	2012	Process modelling of sugar mill biomass to energy conversion processes and energy integration of pyrolysis	Nsaful F (Frank)
SU	Masters	2012	An analysis of the solar service provider industry in the Western Cape	Votteler RG (Roman Guenter)
SU	Masters	2012	Sustainable energy and policy design on the energy transition to renewable energy systems in Stellenbosch, case study: Stellenbosch solar water heater by law	Gosa T (Thumakele)
SU	Masters	2013	East Africa's growing power: challenging Egypt's hydropolitical position on the Nile	Hanke D (Dora)
SU	Masters	2013	Impact of fuelwood quality and quantity on rural households' energy use in Omusati region in North-West of Namibia	Hainduwa F (Feliciana)
SU	Masters	2013	Modelling, design and implementation of a small-scale, position sensorless, variable speed wind energy conversion system incorporating DTC-SVM of a PMSG drive with RLC filter	Bouwer P (Pieter)
SU	Masters	2013	Solar assisted power generation (SAPG): investigation of solar preheating of feedwater	Pierce WT (Warrick Tait)

HEI	Degree type	Year competed	Title	Authors
SU	Masters	2013	Suitability of microwave application to heat reclaimed asphalt and crushed aggregates as an energy efficient method in the production of half warm mix	Nieftagodien R (Riyaaz)
SU	Masters	2013	Wind energy landscapes, place attachment and tourism in the Route 27/West Coast Region of South Africa	Lombard A (Andrea)
UWC	Doctoral	2006	Characterisation of platinum-group metal nanophase electrocatalysts employed in the direct methanol fuel cell and solid-polymer electrolyte electrolyser	Williams M (Mario)
UWC	Doctoral	2008	Proton conducting polymer composite membrane development for direct methanol fuel cell applications	Luo H (Hongze)
UWC	Doctoral	2008	Synthesis of multi-metallic catalysts used for hydrogen and methanol oxidation in fuel cell applications	Naidoo S (Sivapregasen)
UWC	Doctoral	2012	Sustainable utilisation of Table Mountain group aquifers	Duah AA (Anthony Appiah)
UWC	Masters	2006	Synthesis and characterisation of proton conducting membranes for direct methanol fuel cell applications	Mohamed R (Rushanah)
UWC	Masters	2009	Effectiveness of the asset register as a management instrument for the electricity distribution infrastructure within the Stellenbosch Municipality	Gabone D (Derick)
UWC	Masters	2009	Similar solutions for similar problems: harmonising energy trade investment policies and strategies in the East African community	Kikonyogo J (Joseph)
UWC	Masters	2010	Characterisation and chemical speciation modeling of saline effluents at Sasol Synfuels Complex Secunda and Tutuka Power Station	Nyamingura A (Amon)
UWC	Masters	2010	Modeling of the dispersion of radionuclides around a nuclear power station	Dinoko T (Tshepo)
UWC	Masters	2011	Catalyst coated membrane for polymer electrolyte membrane fuel cells	Barraon OC (Olivia Chanel)
UWC	Masters	2011	Electrochemical energy conversion using metal hydrides hydrogen storage materials	Jonas NP (Ncumisa Prudence)
UWC	Masters	2011	The synthesis and characterisation of cathode catalysts to be used in direct methanol fuel cells	Piet M (Marvin)
UWC	Masters	2011	Three dimensional thermal modeling of high temperature proton exchange membrane fuel cells in a serpentine design	Maasdorp LC (Lyndle Caroline)
UWC	Masters	2012	South Africa's policy and legal framework pertaining to sustainable energy generation and use: a critical appraisal	Fourie B
UWC	Masters	2012	Electrochemical characterisation of cathode catalyst for direct methanol fuel cell	Valisi AN (Andiswa Nosipiwo)
UWC	Masters	2013	Comparative analysis of sorghum and other South African grains for sustainable bio-ethanol production	Makaula D (Didi)
UWC	Masters	2013	The contribution of renewable technologies to sustainable community development in Rusitu Valley, Zimbabwe	Mavindidze ZN (Zororo Nyasha)
UWC	Masters	2013	Electrochemical characterisation of platinum based catalyst for fuel cell application	Adonisi T (Thobeka)
UZ	Masters	2006	Energy expenditure and working efficiency of South African sugar cutters	Müller MdeL (Marie De Lanoy)
VUT	Masters	2006	Analysis of environmental impact on the design of fuel cells	Sibiya PM (Petros Mandla)
VUT	Masters	2006	Design and development of a remote monitoring system for fuel cells	Komweru L

HEI	Degree type	Year competed	Title	Authors
VUT	Masters	2006	Development of a 100 W proton exchange membrane fuel cell uninterruptible power supply system	Du Toit JP
VUT	Masters	2006	Development of a high performance zinc-air fuel cell	Lourens D
VUT	Masters	2006	Development of a novel breakfast food product for primary school children in an informal settlement	Kearney JE
VUT	Masters	2007	Development and characterisation of a chitosan fuel cell membrane	Masala A (Aluwani)
Wits	Doctoral	2007	An investigation into increasing the carbon monoxide tolerance of proton exchange membrane fuel cell systems using gold-based catalysts	Steyn J (Johann)
Wits	Doctoral	2007	Pulsed laser deposition of Indium Tin Oxide (ITO), Titanium Dioxide (TiO2) thin films and gold nanoparticles for Dye Sensitised Solar Cells (DSSC) energy applications	Fotsa Ngaffo F (Fernande)
Wits	Doctoral	2007	An investigation into increasing the carbon monoxide tolerance of proton exchange membrane fuel cell systems using gold-based catalysts	Steyn J (Johann)
Wits	Doctoral	2010	A double-sided tubular linear synchronous generator for wave-energy conversion	Joseph DM (Danson Michael)
Wits	Masters	2007	Factors impacting consumer adoption of liquified petroleum gasoline as a vehicle fuel in South Africa	Rajool GF (Godfrey Freddy)
Wits	Masters	2007	Alternative power unit for small, commercial aircraft: design and performance modelling	Bereczky HZ (Horst Zoltan)
Wits	Masters	2007	Identification of characteristic energy scales in nuclear isoscalar giant quadruple resonances: fourier transforms and wavelet analysis	Usman IT (Iyabo Tinoula)
Wits	Masters	2008	Safety management in power system control cetres	Johnson EL (Erica Lizette)
Wits	Masters	2009	Implementing value engineering in green buildings for energy efficiency	Shoniwa MKR (Martin Kurayi Ruramayi)
Wits	Masters	2009	Critical group identification via a radiological habit study of members of the public potentially exposed to radiation from the Koeberg Nuclear Power Station [Research report]	Maree M (Marc)
Wits	Masters	2010	South African consumers' awareness, attitude and behaviour towards energy efficiency	Khatri A (Amal)
Wits	Masters	2010	The decision to install flue gas desulphurisation on Medupi power station: identification of environment criteria contributing to the decision making process	Singleton TC (Tyrone Cloud)
Wits	Masters	2010	Investigation of the release of gaseous fission products from pebble bed modular reactor's triso coated fuel particle during the HFR-H5 fuel irradiation test	Leotlela MJ (Mosebetsi Johannes)
Wits	Masters	2010	Development of software used to analyse the combustion and energy release characteristics of diesel fuels	Da Costa J-P (Jean-Paul)
Wits	Masters	2010	A techno-economic feasibility study on the use of distributed concentrating solar power generation in Johannesburg	Bode CC (Christaan Cesar)
Wits	Masters	2011	The impact of the environmental impact assessment legal regime on mitigation and adaptation to climate change in South Africa	Arenstein GL (Gillian Linda)
Wits	Masters	2011	The legal regulation of renewable energy in South Africa	Hlongwane DA (Dumisani Andrew)
Wits	Masters	2013	Variable flow micro-hydro power generating system	Oerder DF

Appendix 5:
Biographies of Researchers in Energy and Energy-related Research

Bamikole Amigun (NRF-rated[6])

Dr Amigun heads the collaborations and linkages unit of the National Biotechnology Development Agency in Abuja, Nigeria. He holds a doctorate in Chemical Engineering from UCT. He is a bio-energy expert and specialises in the development and application of economic models in renewable energy technologies with a special focus on the African continent. He also specialises in the sustainability assessment and prioritisation of technologies using social, environment and economic indicators; long-term economic viability; risk assessment of energy technologies and process/plant optimisation.

Harold Annegarn (MASSAf, NRF-rated[7])

Professor Annegarn is a Research Professor in the Department of Geography, Environmental Management and Energy Studies at UJ. He is the Director of the Sustainable Energy Technology and Research Centre. His research interests are air quality, global atmospheric chemistry, household energy and remote sensing. He is a member of the Gauteng Advisory Committee to the Department of Economic Development, and Secretary-General of the African Association for Remote Sensing of the Environment.

Christopher Arendse (NRF-rated)

Professor Arendse's research at UWC is focused on the application of nano-structured material in energy conversion devices, such as photovoltaic devices. Specific energy technology areas that he targets are photovoltaic devices, where he focuses on the synthesis and characterisation of silicon-alloyed nano-structures, organic photovoltaics and nano-metrology. Crucial to the development of such devices is the understanding of the structure-property-relationship of the constituent nano-structured material and its eventual impact on the electrical properties and stability of the devices. He has published several papers in international accredited peer-reviewed journals and regularly supervises Masters and doctorates students.

Marinda Bloom

Professor Bloom is a Senior Lecturer in the Department of Microbiology, SU, and obtained her doctorate (microbiology) at the same institution. She has been focusing on microbial enzymes involved in the bioprocessing of high-value agricultural products, with a specific focus on indigenous plant species. Her group focuses on bioprospecting for new enzymes required for lignocellulose hydrolysis. She also acts as Administrative Manager of the Chair of Energy Research.

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6 NRF Rating: The evaluation and rating of individuals is based primarily on the quality of the research outputs of the past eight years. The evaluation is undertaken by national and international reviewers who are requested to critically scrutinise the research completed during the assessment period. Applications are submitted by "established" researchers with a solid track record, or by "younger" researchers who show potential of becoming established within a five-year period or becoming future leaders in their field.

7 MASSAf (Member of ASSAf): Members of ASSAf significantly assist the Academy in achieving its objectives. The primary criterion for election to Membership is significant achievement in the pursuit, advancement or application of science. With its emphasis on evidence-based studies on topics of national importance, ASSAf Members have significant opportunities to apply their knowledge and skills to influence policy and practice.

Alan Brent (NRF-rated)

Professor Brent is a chemical engineer by background and was appointed as a Professor in the Sustainable Development division of the School of Public Management and Planning at SU, where he is also the Associate Director of the Centre for Renewable and Sustainable Energy Studies. He is responsible for the renewable energy policy component of the Sustainable Development Planning and Management academic programme at the Sustainability Institute, where he is now based. His ongoing research efforts aim to improve the planning and management of sustainable technological systems. To this end, he has published over 50 journal articles and a number of chapters in text books, has presented over 40 conference papers in the international sustainability-oriented, and engineering and technology management, communities, and actively participates in the United Nations Environment Programme Global Life-Cycle Initiative.

Michael Brooks

Mr Brooks is a member of the Group for Solar Energy Thermodynamics in Mechanical Engineering at UKZN. His research interests include solar radiometry and solar thermal concentrator development. He is the administrator of the Southern African Universities Radiometric Network and has published several papers on sun strength and its measurement.

Faizal Bux

Professor Bux is the Director of the Institute for Water and Wastewater Technology, DUT. He has been instrumental in establishing the research niche area of wastewater technology and further turning this into the Institute for Water and Wastewater Technology. He has more than 20 years' service at HEIs and has received numerous institutional awards including the Vice-Chancellor's and University Top Senior researcher awards.

Brett Cohen (NRF-rated)

Dr Cohen is Senior Research Officer in the Department of Mechanical Engineering at UCT. His research spans a range of projects which fall at the technology/sustainability interface, and he is currently involved in projects related to national energy systems modelling and alternative energy technology development and deployment. He has extensive experience in stakeholder engagement and is an experienced facilitator on projects related to problem structuring and problem analysis in complex decision problems with multiple stakeholders in the energy sector.

Quentin Campbell

Professor Campbell is a member of the Coal Technology Research Group in the Faculty of Engineering at NWU. His current research topics include: fines beneficiation, fine coal dewatering, dry beneficiation, and coal stockpile dewatering studies. He has been involved in coal studies for more than 15 years, and has 13 accredited journal articles to his credit, as well as over 70 international and local conference papers. He holds a patent and is the author of many industrial research reports. He has acted as study leader or co-study leader for more than 20 doctorate and Masters students.

Keith Cowan

Professor Cowan is Director of the Institute for Environmental Biotechnology (EBRU), RU. He is also owner of AKConsulting and as an independent consultant provides scientific management consulting services to chemical and agrichemical companies, national research funding agencies, other universities, and individual scientists. Prior to joining EBRU he was senior scientist with Nutra-Park Inc, Madison, USA.

Steve Davis

Professor Davis is the R&D Manager at the Sugar Milling Research Institute (SMRI) in Durban. A Professional Chemical Engineer, his research interests include clarification processes, colour removal from sugar juices and syrups, separation technologies and tracer testing. He is responsible for development and effective implementation of the SMRI's research strategy (currently based on transformation of the South African sugarcane processing industry towards a biorefinery-based approach), development of the SMRI's annual research programme and delivery of approved targets against agreed milestones and timelines.

Frank Dinter

Professor Dinter studied Mechanical Engineering and did his doctorate on storage systems for CSP at the University of Essen, Germany. He has worked in several different fields at a utility, heading research and development for fossil-fired power stations and being Head of Solar at Rheinisch-Westfälisches Elektrizitätswerk – Innogy. He was also Technical Director of Andasol 3 (50 MW CSP plant) in Spain. In June 2013, He joined the Faculty of Engineering's Solar Thermal Energy Research Group and holds the Eskom Chair in CSP at SU.

Elsa du Toit

Professor Du Toit is Associate Professor in the Department of Plant Production and Soil Science in the Faculty of Natural and Agricultural Sciences at UP. Her main research interests include the development of plant propagation and cultivation protocols for potential multipurpose crops to be used in biofuel, food, and medicinal industries. She has published more than 20 peer-reviewed scientific articles, two chapters, nine technical reports, and several governmental documents related to the above on biofuels.

Anton Eberhard (MASSAf)

Professor Eberhard is a Professor at UCT where he directs the Management Programme in Infrastructure Reform and Regulation at the Graduate School of Business. He was the founding Director of the Energy and Development Research Centre and is a foundation member of ASSAf. He currently serves on the country's NPC. In 2012, he received the South African National Energy Association's Award for outstanding sustained contribution to the enhancement of the South African energy environment.

Rosemary Falcon

Professor Falcon is the NRF research Chair in Clean Coal Technology at Wits. Falcon held the chair for the last five years while it was still run by the DST and SANERI. She has been involved in coal and carbon research for over 35 years. She is the Director of the Fossil Fuel Foundation of Africa which was founded in 1994 and for two years was President of the Associated Scientific and Technical Societies. She was awarded the Draper Memorial Award from the Geological Society of South Africa, the Southern African Institute of Mining and Metallurgy Gold Medal and the Prestige Award from the Fossil Fuel Foundation.

Jean-Paul Franzidis

Professor Franzidis is a Professor in the Department of Chemical Engineering at UCT. He has been involved in flotation research for over 25 years. His research interests are the characterisation of flotation cells; modelling of flotation pulps and froths and flotation circuit modelling. In 2007, Franzidis joined UCT to direct the newly formed Minerals to Metals Signature Theme. In 2008, he was awarded the NRF Chair in Minerals Beneficiation.

Johann Görgens

Professor Görgens is Senior Lecturer in the Department of Process Engineering at SU and obtained his doctorate (chemical engineering) at the same institution. He has more than ten years of research experience in renewable energy, which includes cultivation processes for ethanol production by recombinant yeast from plant biomass, process modelling and economic evaluation of renewable energy technologies in South Africa.

Louis Johannes Grobler (NRF-rated)

Professor Grobler is a Professor in mechanical engineering at NWU and was appointed as Dean of the Faculty of Engineering in 2012. Apart from lecturing, he also mentors Masters and doctorate students. He has authored or co-authored more than 60 articles on energy-related issues in local and international journals and presented or co-presented more than 80 papers at local and international conferences. He also serves on the technical committee of the International Performance Measurement and Verification Protocol. In 2009, he was elected to the Council of Measurement and Verification Professionals South Africa.

Thomas Harms (NRF-rated)

Professor Harms is a Professor in the Thermo-Fluid Division at SU. He is registered as a Professional Engineer with the Engineering Council of South Africa (ECSA) since 1987 and has been evaluated as a C3-category researcher by the NRF since 2005. His field of specialty is computational fluid dynamics (CFD) and he undertakes research in CFD and (solar) energy systems. He did his doctorate on using a finite volume method for the analysis of flow fields with complex boundaries.

Sue Harrison

Professor Harrison has some 20 years' experience in research in bioprocess engineering, gained in the industrial and academic arenas. She joined the academic staff of the Department of Chemical Engineering at UCT in 1991. Her research in biohydrometallurgy centres on metal extraction from sulphidic minerals through tank and heap bioleaching, sulphate reduction, and acid and metalliferous drainage prevention. She collaborates actively with researchers at the universities of Mumbai, Cambridge and Imperial College London and with companies in South Africa and abroad. She was awarded the DST Research Chair in Bioprocess Engineering, with effect from 2008. She received the "Distinguished Woman Scientist" award in 2008 from the DST.

Lorren Haywood

Dr Haywood is an environmental scientist in the sustainable social-ecological systems research group at the CSIR and focuses on research in the field of environmental management and assessment in the private and public sectors. Her main field of interest is research on policy instruments and their use in contributing to sustainable development and using a systems approach to contribute towards sustainability challenges.

Diane Hildebrandt (MASSAf)

Professor Hildebrandt is the Co-director of the Material and Process Synthesis Research Unit at Unisa. She has authored two books, over 100 scientific papers, including an invited paper in *Science*, and has supervised over 80 postgraduate students. In 2009, she was the winner of the Distinguished Woman Scientist Award of the DST and was also winner of the Continental African Union Scientific Awards for the category Basic Science, Technology and Innovation. She was awarded the ASSAf Gold

Medal for "Science in Society" in 2010. Her research area is the design of energy efficient processes and equipment, with the view to reducing carbon dioxide emissions from chemical processes. Some of these ideas have successfully been implemented in the Golden Nest Fischer-Tropsch pilot plant in Baoji, China and the Linc Fischer-Tropsch plant in Chinchilla in Australia.

Nelson Ijumba (MASSAf)

Professor Ijumba graduated from the University of Dar es Salaam, Tanzania, with a first-class Honours degree in electrical engineering. He obtained his Masters and doctorate degrees in electrical engineering from the Universities of Salford and Strathclyde, respectively. Until 2013 he was the Deputy Vice-Chancellor responsible for research at UKZN and also the Coordinator of the High Voltage Direct Current Centre. He now serves as the Deputy Vice-Chancellor of Academic Affairs and Research at the University of Rwanda. He is a member of the Institution of Engineering and Technology, Institution of Electronic and Electrical Engineers, and a registered professional engineer in UK, South Africa, Kenya and Tanzania. His research interests include high voltage, electrical power and energy systems and impact of technologies on sustainable development.

Sunny Iyuke (NRF-rated)

Professor Iyuke is a Professor of chemical and process engineering and the Head of the School of Chemical and Metallurgical Engineering at Wits. His interests lie in the production of carbon nanomaterials for various applications such as proton exchange membrane fuel cell components, microbrewery, biomedical devices, water treatment and purification, petroleum refining and energy storage. He is a registered Professional Engineer with the ECSA, charted engineer with the Engineering Council, United Kingdom, and a Fellow of the South African Academy of Engineering, amongst others. He is a council member of the South African Institution of Chemical Engineers.

Kalala Jalama

Dr Jalama holds a bachelor and doctorate degrees in chemical engineering. He obtained his bachelor degree from the University of Lubumbashi in the Democratic Republic of Congo and his doctorate degree from Wits, with an exchange programme with Cardiff University in Wales and Aberdeen University in Scotland, United Kingdom. He has worked as senior process engineer at the Centre of Material and Process Synthesis at Wits and was involved in the development of coal-to-liquid facilities. He has also worked as senior process engineer at K'enyuka and was involved in the design of coal processing plants before joining the UJ as Senior Lecturer in 2009.

Neil Jarvis (MASSAf)

Dr Jarvis is a Senior Manager for health and biosciences in the Division of Research and Development at Necsa. He manages the Nuclear Technologies in Medicine and the Biosciences Initiative, a national technology platform to develop innovative products and research tools. He also serves on the Programme Management Committee of the African Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology. He has been the recipient of several awards, including the South African Chemical Institute's Raikes Medal in 1994 and the Necsa Chairperson's Award as the company's top performer.

Graham Jewitt

Professor Jewitt is Professor of Hydrology at UKZN and received his doctorate in 1998. He has (co)-authored over 20 peer-reviewed publications and supervised the completion of several Masters and doctorate degrees. His research interests include: land use hydrology, (assessing the impacts of land uses on water resources), water-related policy implementation, and the development of agricultural water management technologies for small-scale farmers. Jewitt is active in several international research initiatives with partners in South Africa, Tanzania, Zimbabwe, Namibia, Botswana, France, Netherlands, Sri Lanka Sweden and the United Kingdom.

Rufaro Kaitano

Dr Kaitano holds a doctorate in coal characterisation and gasification kinetics modelling from NWU, and is affiliated to the Coal Research Group at NWU. He is a chemical engineering lecturer and is involved in clean coal technology research at Masters and doctorate levels. The research group focuses on finding cleaner ways of utilising coal for energy generation and minimising the negative environmental impact associated with coal usage as a source of energy.

Azeem Khan

Dr Khan received his bachelors, Masters and doctorate degrees in electrical engineering from UCT. He worked previously at Koeberg Nuclear Power Station in South Africa as a maintenance engineer and system engineer on the turbine and generator control systems. He also spent two years at Clarkson University, New York, USA, where he taught a semester course in energy conversion and worked on several research projects for New York State Energy Research and Development Authority and several companies, including Warner Energy and Advanced Machines & Drives. He is currently with the Department of Electrical Engineering at UCT, where he is an Associate Professor. His research interests are in permanent magnet machine design, and control of wind energy systems.

Wim Jonker Klunne

Dr Klunne's field of expertise is hydropower. He has worked on a wide range of education, research and implementation projects around the world on behalf of the African Development Bank, the World Bank, Energy Research Centre of the Netherlands, United Nations Development Programme, and the Global Environment Facility. Currently he is working at the CSIR as Senior Researcher on renewable energy and energy efficiency projects and is involved in a large number of projects ranging from support to Eskom on renewable energy capacity planning, capacity building on SMEs, energy management and energy efficient buildings. He is currently conducting doctorate research at the University of Twente, Netherlands, on the sustainability of small hydropower projects in eastern and southern Africa.

L Xinying Lui

Dr Liu has been working in the area of heterogeneous catalyst and nano-materials since he obtained his doctorate in chemistry in Nankai University, Tianjin, China in 1999 and as a postdoctoral Fellow at Wits. He became a project technical leader of a coal-to-liquid pilot plant in a private company in 2004 and was involved in the commercial and engineering phase of the pilot project. He then joined the Centre of Material and Process Synthesis, Wits, as a consultant in 2007 taking charge of the Fischer-Tropsch research group and industrial project development. In 2013, he joined the Material and Process Synthesis Research Unit at Unisa as a Senior Researcher.

Dheepak Maharajh

Mr Maharajh, Senior Scientist in the Bioprocess Development Research group of the CSIR, holds a Masters bioprocess engineering qualification from US. His current research interests are biofuels, biodiesel from algae and fermentation. He has made a meaningful contribution in a new field of algal biodiesel. He further initiated the first algal bioprospecting project for lipid-producing organisms in South Africa.

Sampson Mamphweli

Dr Mamphweli is a Senior Researcher at the UFH, Institute of Technology. He obtained a doctorate in physics from UFH and a Masters degree in environmental sciences from the University of Venda. He also received a certificate in Financing Renewable Energy and Energy Efficiency from the Renewables Academy based in Germany and the GreenPower mini-master of business administration from the GreenPower Academy based in Britain. He conducts research on renewable energy technologies and their applications, and he is a respected authority in the biomass to energy field. His current area of research interest includes biomass gasification for electricity generation, biogas digesters, co-gasification of coal and biomass for electricity generation as well as solar energy technologies.

Regina Maphanga

Professor Maphanga is an Associate Professor at the Materials Modelling Centre, UL and a Junior Associate at the Abdus Salam International Centre for Theoretical Physics in Italy. She completed her doctorate in physics in 2005. Her research focuses on computational modelling of cathode materials for lithium-ion batteries for use in energy storage devices. She is currently a member of the South African Young Academy of Science (SAYA).

Andrew Marquard

Dr Marquard is a Senior Researcher in the Energy, Environment and Climate Change research group at UCT. His research focuses on energy-related climate change mitigation, as well as South African energy policy and governance, and draws on a wide range of skills, including energy analysis and modelling and policy analysis. He also teaches energy studies at a postgraduate level. His most recent reports, generally co-authored with other members of the programme, have included an "Analysis of the economic implications of a carbon tax"; "Analysis of possible quantified emission reduction commitments by individual Annex I Parties"; and "Economics of climate change: Context and concepts related to mitigation".

Rethabile Melamu

Ms Melamu holds a Masters degree in chemical engineering from UCT. Her research focus is environmental assessments and analyses of processes and products, including environmental life-cycle analyses, solid waste management options, in particular, investigating options for harnessing energy from waste. She has experience in the area of waste-to-energy both in research and project implementation. Her experience spans from setting up of bio-digesters in urban areas, from conceptual design phase to implementation and operation. She won the Specialisation Award in the South African Annual Chemical Technology Awards 2010 under Energy category for the project she managed which entailed setting up a bio-digester fed solely on canteen food waste.

Edson Meyer (NRF-rated)

Professor Meyer is Executive Director of the Institute of Technology at UFH. During his time at UFH he has been actively involved in research with Masters and doctorate students in the fields of advanced engineered materials, renewable energy, energy efficiency, information and communication technology and power engineering. These research activities have a strong community engagement aspect to it. In addition to his academic qualifications, Edson is a certified energy manager and certified measurement and verification professional. He is also the founder and Chief Executive Officer of a closed corporation, WattMore Power Solutions, focusing on renewable energy technologies and energy efficient initiatives.

Josua Meyer (NRF-rated)

Professor Meyer is a Professor and Head of the Department of Mechanical and Aeronautical Engineering at UP. He is also the Chair of the School of Engineering. He specialises in heat transfer, fluid mechanics and thermodynamic aspects of heating, ventilation and air-conditioning. He is the author and co-author of more than 300 articles, conference papers and patents and has received various prestigious awards for his research. He is also a Fellow or member of various professional institutes and societies, such as the South African Institute for Mechanical Engineers, South African Institute for Refrigeration and Air-conditioning, American Society for Mechanical Engineers, American Society for Air-conditioning, Refrigeration and Air-conditioning. He has received various teaching and exceptional achiever awards. He is an associate editor of Heat Transfer Engineering and editor of Experimental Heat Transfer.

Theo Muller

Dr Muller is a material scientist at the UWC. His research centres on photovoltaic material for the generation of electricity. In particular, it focuses on the application of nanoparticles for improving the charge-transfer mechanisms, and ultimately the efficiency of these devices. The features of nano-silicon and its alloys in silicon thin film photovoltaics, and metal and metal oxides used in silicon and organic photovoltaics, are specifically studied so that the structural and optical properties can be related to device performance. Whilst registered at UWC for his doctorate he was awarded the Utrecht University Africa Fellowship, and spent six months in the Netherlands to further his experimental work.

Josiah Munda

Dr Munda holds an engineering doctorate in electrical engineering from the University of the Ryukyus, Japan. He was appointed Associate Professor of electrical engineering at TUT in November 2004, and is the Director of the Centre for Energy and Electric Power. His main research areas are power system stability, renewable energy, distributed generation systems, energy management, microgrids and intelligent control of hybrid power systems. He is a member of the Institute of Electrical and Electronics Engineers and South African Institute of Electrical Engineers.

Kenneth I Ozoemena (NRF-rated)

Professor Ozoemena is a Principal Researcher and Research Group Leader of the Electrochemical Energy Technologies at the CSIR, focusing mainly on electrochemical energy storage and conversion systems (fuel cells, lithium-ion batteries and electrochemical capacitors/supercapacitors) and dye sensitised solar cells.

Anastassios Pouris (MASSAf, NRF-rated)

Professor Pouris obtained his Masters degrees in management engineering from the Aristotelian University of Thessaloniki, Greece and in applied economics from the University of Surrey, England. He received his doctorate from UCT in energy policy-related issues. He received his executive education at the JF Kennedy School of Government at Harvard University and the International Institute of Management Development, Switzerland. His research focus is the management and evaluation of science, energy economics and performance; technology and innovation systems and the transfer and adoption of best practice in the South African reality. He is Member of ASSAf and of the Research, Innovation Strategy Group of Higher Education South Africa. He has also testified in a number of Parliamentary committees.

Alex Quandt

Professor Quandt received his doctorate in physics from the Eberhard-Karls University of Tuebingen, Germany, in 1997. In 2001, after postdoctoral Fellowships at Cornell University and Georgetown University, he joined the Physics Department of Greifswald University, Germany, as an Assistant/Associate Professor. Since 2010 he has been an Associate Professor of Theoretical Solid State Physics at the School of Physics, at Wits, where he also acts as Focus Area Coordinator at the Department of Science and Technology/ NRF Centre of Excellence in Strong Materials. His research interests are computational materials science, aperiodic solids, order and disorder phenomena, photonics/plasmonics, and materials for energy.

Thomas Roos

Mr Roos is a mechanical engineer specialising in gas turbine fluid dynamics, heat transfer (in general and specifically in gas turbine hot end components, particularly gas turbine blades and discs), and renewable energy, specifically solar thermal technologies at the CSIR. He has 14 years' experience in gas turbine design and analysis of performance and heat transfer.

Adoniya Ben Sebitosi (NRF-rated)

Professor Sebitosi is a Professor in the Department of Mechanical and Mechatronics Engineering at SU. He has been registered as a chartered engineer with the Engineering Council of the United Kingdom since 2003, with the Engineers Registration Board of Kenya since 1987 and is evaluated as a C3-category researcher by the NRF since 2009. His field of specialty is applied solar energy systems modelling and rational use of energy. He did his doctorate on the application of advanced automotive technologies to rural electrification.

Jeff Smithers

Professor Smithers is head of the School of Bioresources Engineering and Environmental Hydrology at UKZN. He joined the former University of Natal as a Senior Research Fellow in 1989. Since then, he has steadily moved up through the ranks and was appointed Head of School in 2002. He is a prolific researcher in the field of engineering and design hydrology and hydrological modelling and is a sought-after consultant on issues relating to his field of expertise.

William Stafford

Dr Stafford is a Senior Researcher in the Natural Resources and the Environment Unit of the CSIR. He holds a doctorate in molecular biology and biochemistry of malaria (University of London) and has been actively involved in academic research and development for over ten years. He is interested in using integrated systems thinking to develop the tools, models and mechanisms required for sustainable development.

Christien Strydom (NRF-rated)

Ms Strydom is Director of the School of Physical and Chemical Sciences at NWU and is part of the Chemical Resource Beneficiation Focus Area at NWU. Her research interests are coal and biomass chemistry. She has been awarded by UP the Faculty of Science award for best performance as a lecturer and researcher under 35 years, the South African Chemical Institute prestigious Raikes medal and her innovation research project (Magnesium Compounds Consortium) was selected by the NRF and the dti as one of the ten best innovation fund's projects up to 2004.

Karen Surridge-Talbot

Dr Surridge-Talbot holds a doctorate in microbiology from UP. Her career encompasses a variety of topics over the last ten years working with the energy field. Currently she is the Centre Manager of the Renewable Energy Centre of Research and Development (RECORD) at SANEDI. RECORD aims to facilitate renewable energy research coordination, collaboration and dissemination of national and international renewable energy knowledge contributing towards a sustainable low carbon energy future. Dr Surridge-Talbot serves as an Extraordinary Lecturer at UP in the Department of Plant Production and Soil Science in the Faculty of Natural and Agricultural Sciences. She also holds a position on the council of the South African Coal Ash Association.

Christina Trois (NRF-rated)

Professor Trois is currently Associate Professor and Head of the School of Civil Engineering, Surveying and Construction in the Faculty of Engineering at UKZN. She is co-founder of the Centre for Research in Environmental, Coastal and Hydrological Engineering in the same school. She has developed and successfully coordinated the Masters programme in environmental engineering since 2001. She is a C2-rated scientist with the NRF and her main fields of expertise are environmental and geo-engineering, waste management, wastewater treatment, renewable energy from waste and greenhouse gas control from zero waste in Africa and developing countries.

Rob van Hille

Dr Van Hille has over 15 years of research experience in the fields of environmental biotechnology and biohydrometallurgy. He currently holds the position of Senior Research Officer within the Centre for Bioprocess Engineering Research at UCT. Upon completion of his doctorate, he spent two and a half years as a postdoctoral researcher in the Crystallisation and Precipitation Research Unit at UCT, working on a diverse range of projects from fundamental studies on metal sulphide precipitation and carbonation of alkaline brines to concrete corrosion and reverse osmosis membrane degradation.

Daan van Wyk (MASSAf)

Professor Van Wyk is Visiting Professor at UJ. Formerly he was J Byron Maupin Professor of Engineering at the Virginia Polytechnic Institute and State University (VPISU) in Blacksburg, Virginia, United States and Research Leader, National Science Foundation Engineering Research Centre for Power Electronic Systems, VPISU. He was the founding Chairman of the Department of Electrical and Electronic Engineering at the Rand Afrikaans University (now UJ), founding Dean of engineering and Vice-Rector of the university. He received the Havenga Prize of the *Suid-Afrikaanse Akademie vir Wetenskap en Kuns* in 1989.

Emile van Zyl

Professor Van Zyl is the Senior Chair of Energy Research in Biofuels and other alternative clean fuels at SU and he is also a Professor at the Department of Microbiology. His laboratory is well established in the microbiology and biochemistry of plant degrading enzymes and he has gained international recognition as research leader in the development of recombinant yeast for biofuel production from total plant biomass. In his capacity as Chair, he steers a large research programme at SU towards the development of advanced second generation technologies for the conversion of total plant biomass to biofuels.

Herman Vermaak

Professor Vermaak is currently the Head of the Electrical, Electronic and Computer Engineering Department at CUT. The department has been offering the Higher Certificate in Renewable Energy Technologies in January 2014. His research interests are optimising the use of renewable energy technologies and reconfigurable assembly and manufacturing systems. He is involved in various projects concerning the greening of the CUT campus in Bloemfontein.

Theo von Backström (NRF-rated)

Professor Von Backström is currently appointed as a Senior Researcher and Emeritus Professor in the Thermo-Fluid Division at SU. In 1970 he was registered as a professional engineer with the ECSA and is currently evaluated as a B2-category researcher by the NRF. He did his doctorate on the maximisation of pressure recovery in diffusers with specific inlet conditions. He conducts research in the fields of turbomachinery and fluid dynamics.

Harro von Blottnitz

Professor Von Blottnitz is a Professor at UCT. He holds bachelor and Masters degrees in chemical engineering from this institution, and a doctorate in engineering from the Rheinisch-Westfaelische Technische Hochschule, Aachen, Germany. His research interests are inspired by the multiple challenges of sustainable development in the resource industries, especially in developing country settings, and span topics in the fields of environmental systems analysis, bio-fuels processing, and waste management, especially in the contexts of the mining industry and in African cities.

Graham von Maltitz

Mr Von Maltitz is a senior researcher, Natural Resources and the Environment, CSIR. He is a systems ecologist and rural development specialist, employed by the CSIR since 1989. He obtained his Masters from Wits in 1990 and is currently registered for a doctorate through NMMU. He has specialised in large integrated multidisciplinary projects involving the interface between humans and natural resource management.

Frederik van Niekerk

Professor Van Niekerk is Deputy Vice-Chancellor: Research, Innovation and Technology at the North-West University. He obtained his BSc (Mathematics, Applied Mathematics and Physics), Hons BSc (Applied Mathematics), MSc (Physics) and DSc (Reactor Science) at Potchefstroom University. He is a registered Professional Scientist with SACNASP. His scientific work included work on neutron noise, condition monitoring systems, systems engineering. His career in innovation management and leadership includes academic and management positions at the North-West University and senior management positions at the South African Nuclear Energy Corporation, Denel Aviation and the Pebble-bed Modular Reactor.

Wikus van Niekerk (MASSAf, NRF-rated)

Professor Van Niekerk is Professor in the Department of Mechanical and Mechatronic Engineering and Director of the Centre for Renewable and Sustainable Energy Studies at SU. He is registered as a Professional Engineer with the ECSA, and is currently evaluated by the NRF as a C2 internationally recognised researcher. He is regularly consulted by industry on a variety of areas, including noise and vibration, especially human response to noise and vibration, noise-vibration-harshness, vehicle dynamics, renewable energy systems and wave energy.

Zeblon Vilakazi (MASSAf)

Professor Vilakazi was recently appointed as Deputy Vice-Chancellor for Research and Postgraduate Affairs at Wits. He was Director of iThemba LABS and also served as Group Executive for research and development at Necsa. He is an Extraordinary Professor at UP and a member of the Board of the Nuclear Industries Association of South Africa and a member of the Council of ASSAf.

Frans Waanders (NRF-rated)

Professor Waanders is a Professor at the School of Chemical and Minerals Engineering, NWU. He completed his doctorate in nuclear physics in 1984 at NWU. His field of specialisation is coal gasification. He has a C1 NRF-rating from 2009. He authored/co-authored more than 100 publications of international standard and he was part of the three-man team that worked towards the Vredefort Dome being proclaimed as a World Heritage Site in 2005.

Harald Winkler (NRF-rated)

Professor Winkler was appointed Director of the Energy Research Centre at UCT in April 2013. His research interests are focused around climate policy, at international and national level. He led the research work underpinning South Africa's Long-term Mitigation Scenarios. His current work includes work with other developing countries to share the LTMS experience in a programme called Mitigation Action Plans and Scenarios. Research areas have included equity and future commitments to climate action; economics of climate change mitigation; energy scenarios for South Africa and Cape Town; the links between sustainable development and climate change; and renewable energy and mitigation.

Xiaohua Xia (MASSAf, NRF-rated)

Professor Xia is a Professor in the Department of Electrical, Electronic, and Computer Engineering at UP, South Africa, and the Director of both the Centre of New Energy Systems and the National Hub for Energy Efficiency and Demand Side Management. He is a Fellow of the Institute for Electronic and Electrical Engineers, a Member of the Academy of Science of South Africa, a Fellow of the South African Academy of Engineering, and he has an A-rating from the NRF. He also serves as the Chair of the Technical Committee of Non-linear Systems of the International Federation of Automatic Control. His research interests include non-linear feedback control, observer design, time-delay systems, hybrid systems, modelling and control of HIV/AIDS, control and handling of heavy-haul trains and recently, energy optimisation systems.

Jiangfeng Zhang (NRF-rated)

Professor Zhang is an Associate Professor at the Department of Electrical, Electronic and Computer Engineering at UP. His research interests include energy system modelling and optimisation, measurement and verification, nonlinear control systems, global optimisation, and computer algebra. He is involved in a number of energy efficiency projects. His research plan for the next five years will focus on the energy optimisation of buildings and renewable energy systems.

Notes

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